US Army Corps of Engineers
Waterways Experiment Station

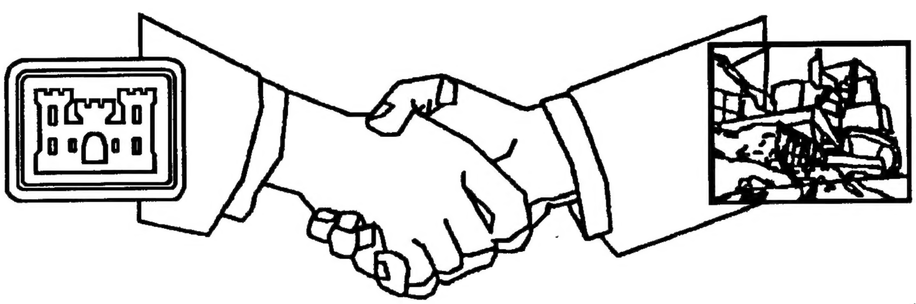
Final Report
CPAR-GL-97-3
July 1997

CONSTRUCTION PRODUCTIVITY ADVANCEMENT RESEARCH (CPAR) PROGRAM

Development and Demonstration of Dredged Material Containment Systems Using Geotextiles

by

Paul Gilbert, Jack Fowler, Ed Trainer



A Corps/Industry Partnership to Advance Construction Productivity and Reduce Costs

Construction Productivity Advancement
Research (CPAR) Program

Technical Report
CPAR-GL-97-3
July 1997

Development and Demonstration of Dredged Material Containment Systems Using Geotextiles

by Paul Gilbert, Jack Fowler

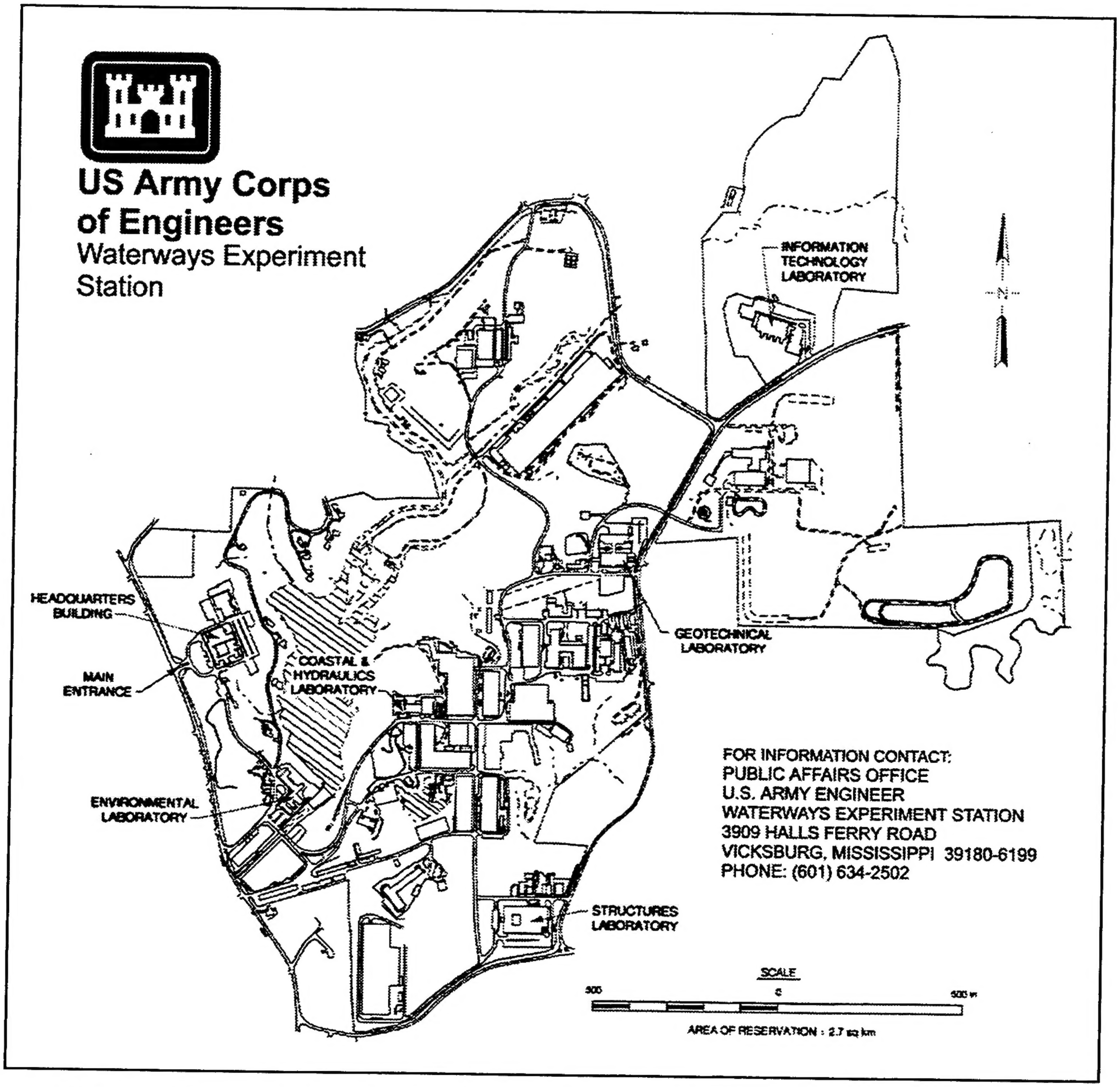
U.S. Army Corps of Engineers
Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Ed Trainer

Nicolon Corporation
Norcross, GA

Final report

Prepared for U.S. Army Corps of Engineers
Washington, DC 20314-1000



Waterways Experiment Station Cataloging-in-Publication Data

Gilbert, Paul A.
Development and demonstration of dredged material containment systems using geotextiles / by Paul Gilbert, Jack Fowler, Ed Trainer ; prepared for U.S. Army Corps of Engineers.
84 p. : ill. ; 28 cm. — (Technical report ; CPAR-GL-97-3)
Includes bibliographical references.
1. Geotextiles. 2. Dredging spoil — Environmental aspects. 3. Slurry. I. Fowler, Jack , 1938- II. Trainer, Ed. III. United States. Army. Corps of Engineers. IV. U.S. Army Engineer Waterways Experiment Station. V. Geotechnical Laboratory (U.S. Army Engineer Waterways Experiment Station) VI. Construction Productivity Advancement Research Program (U.S.) VII. Title. VIII. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; CPAR-GL-97-3.
TA7 W34 no.CPAR-GL-97-3

Contents

List of Figures

List of Tables

Preface

The study reported herein was conducted by the Geotechnical Laboratory (GL), U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS, for Headquarters, U.S. Army Corps of Engineers (HQUSACE) as part of the Construction Productivity Advancement Research (CPAR) Program. The industry partner for this study was the Nicolon Corporation of Norcross, GA. The HQUSACE Technical Monitors were Messrs. Jeng I. Chang and Barry Holliday.

This study was conducted under the general supervision of Dr. W. F. Marcuson III, Director, GL, and Dr. Don Banks, Chief, Soil and Rock Mechanics Division (S&RMD), GL. This report was produced under the direct supervision of Mr. Robert D. Bennett, Chief, Soils Research Facility (SRF), GL. Personnel assisting in the collection and compilation of the data for this study include Dr. Jack Fowler, formerly of the Soil Mechanics Branch (SMB), GL, before retirement in 1994, and Mr. Ed Trainer of the Nicolon Corporation. Dr. Fowler's involvement in the project continues as consultant for the Nicolon Corporation. This report was prepared by Dr. Paul Gilbert, SRF, with input from Dr. Fowler and Mr. Trainer. This report is the final report for the CPAR project entitled "The Development and Demonstration of Dredged Material Containment Systems Using Geotextiles."

During this investigation, Dr. Robert W. Whalin was the Director of WES. COL Bruce K. Howard, EN, was the Commander.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
cubic inches	0.00001638706	cubic meters
cubic yards	0.7645549	cubic meters
degrees (angle)	0.01745329	radians
Fahrenheit degrees	5/9	Celsius degrees or Kelvin[1]
feet	0.3048	meters
feet per second	0.3048	meters per second
pounds (force)	4.448222	Newtons
inches	2.54	centimeters
miles (U.S. statute)	1609.347	meters
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic meter
pounds per linear inch	17.85797	kilograms per meter
tons (2,000 pounds, mass)	907.1847	kilograms

[1] To obtain Celsius (C) temperature from Fahrenheit (F) readings, use the following formula: C = (5/9)(F-32). To obtain Kelvin (K) readings, use: K + (5/9)(F-32) + 273.15.

1 Introduction

The CPAR Program

The U.S. Army Corps of Engineers Construction Productivity Advancement Research (CPAR) Program is a cost-shared research and development program to facilitate development and application of advanced construction techniques and technologies. The program permits the Corps of Engineers to enter into an agreement with U.S. construction industry representatives and assist in the advancement and promotion of ideas and technologies that will have a direct positive impact on U.S. construction productivity. The CPAR program has received excellent support from the U.S. construction industry, and numerous projects have been funded and successfully developed since introduction of the program in 1989.

In 1994 the U.S. Army Engineer Waterways Experiment Station (WES) and the Nicolon Corporation of Norcross, GA, signed a Construction Productivity Advancement Research Program Cooperative Research and Development Agreement (CPAR-CRDA) to begin a multiyear joint research project on the development and use of geotextile systems for the containment and placement of dredged materials. This report describes and summarizes some of the activities and findings of that research.

Objectives

The objectives of this study were to develop and demonstrate dredged material containment systems that are environmentally sensitive and cost effective for the handling and disposal of dredged materials, and to produce methodology for analysis and design of the containment systems. Containment is provided by fabricated geotextile tubes and containers which, when filled, can be used to construct engineered earth mounds above and below water.

2 Geosynthetic Products and Technology

Background

Geosynthetics are a class of products manufactured from polymeric materials that are used in soil and/or rock structures to facilitate construction. Geosynthetic fabrics or geotextiles are tough, flat sheets typically made of synthetic fibers produced from polymeric materials that are woven, knitted, punched, melted, resin treated, or simply pressed together. Woven and knitted sheets are termed woven geotextiles, and sheets that are pressed, matted, heat bonded, resin treated, or punched together are termed nonwoven geotextiles.

The fibers of woven and knitted geotextiles are systematically plaited together; consequently, they have higher (tensile) stiffness, strength, and abrasion resistance than corresponding nonwoven geotextiles that are held together by random entanglement of the fibers. Nonwoven geotextile sheets that are punched through with barbed needles to facilitate entanglement of the fibers are termed needle punched. Heat-bonded geotextiles are thermally bonded by melting the fibers to form weld points. Resin-bonded geotextiles are sprayed or impregnated with acrylic resin that forms strong bonds between fibers after curing.

Geotextile sheets may be made from natural materials and fibers; however, those made from synthetic materials show great resistance to chemical degradation and damage from biological activity. Some properties of synthetic fibers are shown in Table 1 (Koerner 1994). As can be seen in Table 1, the specific gravity of some listed polymers is less than 1.0; therefore, they are less dense than water and will float. This fact must be considered when contemplating underwater work with geotextiles.

Many geotextiles are available in 5- to 8-m- (15- to 25-ft-) wide sheets that are easily sewn together to form composite systems to perform specific functions. A major advantage of geotextiles is that they allow the movement of water both across and within their manufactured plane. Therefore, they facilitate drainage and increase the strength of soil. In addition to facilitating drainage, geotextiles are used to achieve some combination of soil reinforcement, separation, and filtration.

Table 1
Some Properties of Synthetic Fibers (Koerner 1994)

Fiber	Total Industry Output, percent	Specific Gravity	Moisture Regain percent	Melting Point °F/°C
Polypropylene	83	0.91	3.0	325/163
Polyester	14	1.22 or 1.38	0.4 or 0.8	480/249
Polyethylene	2	0.96	2.0	-
Polyamide (nylon)	1	1.14	4.0-4.5	414/212 to 428/220

In the interest of clarity, the distinction is made here between the terms filtration and drainage as used in the geosynthetics industry (Koerner 1994): If water is removed from soil as the result of flow across the manufactured plane of a geotextile, the process is called filtration. Whereas, if water is removed from soil as the result of flow within the manufactured plane of a geotextile, the process is called drainage. However, in the final analysis, water removal by any means or by any definition serves to decrease pore pressure, decrease the volume, and increase density and strength of a soil-water mixture.

Some desirable characteristics of geotextiles are thinness, light weight, good quality control, and ease of installation. Because of enhanced reinforcement, drainage, separation, and filtration of soil and earth materials provided by geotextiles, innovative and cost-effective solutions to geotechnical construction problems are sometimes achieved in situations where no solution is possible using conventional methods and approaches. Examples of potential applications of geosynthetic shell structures for containment and dewatering of soils are given by Fowler, Bagby, and Trainer (1996) in Table 2. Many of the applications listed in Table 2 are described by Sprague and Fowler (1994) and by Pilarczyk (1995). All of the (many) applications listed and described are associated with advantages gained by encapsulating and draining soil. The present investigation is concerned with developing and demonstrating systems for efficiently and effectively handling dredged material. The development and use of such geotextile systems is described below, and they too are based on encapsulating and removing water from soil and soil-like materials.

Geocontainers®, Geobags®, and Geotubes®

Woven and nonwoven permeable synthetic fabrics have been used for the past 30 years to construct various types of soil containers/receptacles such as sandbags, geotextile tubes, and geotextile containers. Such devices have been used in

Table 2
Potential Geobag®, Geotube® and Geocontainer® Applications[1]

1. Dewatering Applications

Fine-grained dredged material
- Clean material
- Contaminated material

Municipal sewage sludge
- Sewage sludge lagoon
- Digester sludge

Water treatment plants
- Lime waste
- Aluminum sulfate waste

Animal waste lagoons
- Pork farms
- Protective dairy farms
- Chicken farms
- Cattle farms

Paper mills
- Waste water lagoons
- Water filtration

Fly ash
- Coal power plants (wet and dry)
- Municipal waste (wet and dry)
- Paper mills
- Lumber mills

Potash lagoons
Phosphate lagoons
Radon-contaminated sheetrock waste
Drilling mud and cuttings (oil and gas wells)
- Onshore
- Offshore

Mine tailings
- Oil shale
- Iron ore
- Copper
- Silver
- Gold

2. Drainage Runoff Applications

Airfields
Automobile parking areas
- Supermarkets
- Shopping centers

Highways
Residential areas
Farming operations
Industrial areas
Mining operations
Oil spills

3. Structural Applications

Dikes
Flood protection dikes
- Permanent structures
- Temporary structures (FEMA)

Containment dikes
Subdivision dikes
Spur dikes
Underwater control dikes
- Contraction dikes
- Saltwater wedge control
- Thalweg control dikes
- Bendway weirs

Mud flat dikes
Hurricane protection dikes
Dike breach repair

Coastal
Groins
Offshore wave breakwaters
Beach nourishment
Shoreline structures
On shore and off stability shore berms
Coastal sand dune protection

Rivers
Thalweg sill structures
Contraction dikes
Shoreline structures
Temporary and permanent flood protection dikes

Wetlands
Containment islands
Wetland construction
Wetlands protection
Wildlife habitat
- Oyster reefs
- Fishing reefs

General Use Categories
Stability berms
Erosion control
Water outfall protection
Weirs
Gully repair
Desert sand dune protection
Silt fence
Rock slide, snow drift, and avalanche protective structures
Noise abatement structures
Walls
Barricades
- Domestic
- Military applications (explosives, equipment, and personnel protection)

Roadways (encapsulated soil)
Surcharge for dewatering applications
Ballast applications for pipelines
- River crossings
- Soft soils
- Frozen soils (permafrost)

4. Erosion and Scour Protection Applications

Bridge piers and piling
Tunnels

(Continued)

[1] From Fowler, Bagby, and Trainer (1996).

Table 2 (Concluded)	

Pipeline crossings
Utility cable crossings
Walls
Abutments
Foundations
Wharf supports
Offshore drill rig supports
Rock groins and jetties
Wind erosion
 	
5. Containment of Contaminated Materials
 	
Containment of fine-grained dredged material
    Navigation channels
	Ship and marina docking areas
	Lakes
	Golf course ponds
	Containment and placement of contaminated dredged materials
	    Continental shelf
	    Abyssal planes
	Capping contaminated materials
	Hazardous and toxic wastes (polychlorinated biphenyls, polynuclear aromatic hydrocarbons, heavy metals, pesticides, etc.)
	Industrial and paper mill waste
	Sewage sludge

The Netherlands and Germany as "training" structures[1] for rivers and for shoreline protection. The terms geobag®, geotube®, and geocontainer® (which refer to sandbags, geotextile tubes, and geotextile containers, respectively) are registered trademarks of the Nicolon Corporation and are used in this report. A general definition and description of the devices are necessary and will follow.

Geocontainers®

A geocontainer® is a tubular unit with pillow-shaped ends; it is constructed of a soil-tight geotextile system that can be mechanically or hydraulically filled with soil. The purpose of the geotextile system is to allow the removal of water while retaining soil particles; it may consist of a single layer, but may also consist of multiple layers if it is necessary to provide one or more liners to prevent the escape of fine soil particles.

Originally, geocontainers® were designed to conform to the shape of, be filled within, and be discharged from the hopper of a split-hull scow. Units up to 120 ft long and 45 to 60 ft in circumference have been successfully constructed, filled with 500 to 600 tons of soil, and placed in 60 to 70 ft of water flowing with surface currents up to 5 ft/sec. Geocontainers® may be used for the encapsulation and placement of contaminated or otherwise undesirable soils or may be filled with clean material and used as structural elements for underwater construction.

Geobags®

A geobag® is a miniature geocontainer®. These units may vary in size from 2 to 10 ft in circumference and 2 to 10 ft in length and may be filled with from 100 lb to 4 tons of soil or cement grout. They are used primarily as structural elements in the construction of soil embankments, dikes, and groins either above or below

[1] "Training" structures are those placed in a river in the attempt to control its depth, flow patterns, currents, and course.

water. Like geocontainers®, geobags® have been successfully placed in water up to 70 ft deep with surface currents up to 5 ft/sec.

Geotubes®

A geotube® is a long cylindrical tube with pillow-shaped ends that is constructed of a soil-tight geotextile. The structures are sometimes called soil sausages (Silvester 1986) or soil pillows (Perrier 1986). These units are hydraulically filled and used as encapsulated soil structural elements. Geotubes® hundreds to thousands of feet long have been built to serve as dikes, embankments, groins, and breakwaters either above or below water. Geotubes® may be pumped full of slurry with low soil solids content; consequently, there is substantial volume decrease as drainage takes place and the soil solidifies. If this is the case, several fillings (and subsequent periods of drainage) are necessary to attain the tube height required in a final structure.

A major advantage of geotubes® is that they are able to make use of high-water-content, low-strength soils that would otherwise be unusable as construction material. The disadvantage is that time is required for these materials to drain and solidify and several fillings are generally required. Geocontainers® and geobags® are mobile to the extent that they may be filled at one location and transported by truck or barge to their final destination. Geotubes® are stationary in that they are constructed in the location where they will remain.

Inlet Spacing on Geotubes®

During installation, the geotextile shell for a tube is rolled out along the intended alignment with inlets for filling centered on top. Spacing of the inlet ports is a matter for concern since it is important that the slurry flows to fill the tube with a relatively smooth and level top surface. In this sense, proper inlet spacing is determined by the settling characteristics of the soil being placed. For example, if the soil being placed settles very quickly in water and distance between inlets is too great, then the particles "pile up" near the inlet. A situation ranging from an undulating top surface to a complete blockage of the tube is the result. If a geotube® is to be placed in water, the buoyancy of the geotextile shell and inner liners must be considered as well as the settling characteristics of the soil placed inside the tube.

Sand particles settle so quickly that when filling geotubes® with soils high in sand content, it may be necessary to use an impermeable liner inside the tube because the movement of sand particles is aided by the water. If too much water is lost too quickly through a very pervious geotextile shell, then the sand particles do not flow into the tube, but "pile up" near the inlet port. An impermeable liner slows down the escape of water and maintains a flowable sand/water mixture inside the tube, thereby allowing the sand particles to be transported longer distances inside the tube.

Conversely, fine clay particles settle so slowly in water that transport of clay/ water mixtures over long distances occurs readily, even at low slurry velocity. However, fine particles may flow through the geotextile shell along with the transport water to result in the release of an unacceptably high level of solids in the discharge water. Therefore, a permeable liner to serve as a filter to retain fine clay particles may be necessary.

Inlets/filler tubes are normally spaced along the length of a geotube® at about 33-m intervals, depending on sedimentation characteristics of the soil; spacing may be increased or decreased as required (Sprague and Fowler 1994). Bogossian et al. (1982) describe filling geotextile "sausages" nominally 1 m in height in Brazil. These tubes were filled with clay balls where the inlets were spaced every 8 m, and with a clayey sand (or sandy clay) where the inlets were spaced 20 m apart. These spacings were chosen because the clay balls and clayey sand were determined to spread (repose after being pumped in a water carrier) at slope angles of 1V:8H and 1V:20H, respectively. The clay balls described by Bogossian et al. (1982) were up to 10 cm in size and were transported in a slurry containing an organic clay; the sandy clay had a friction angle of 15 deg and a saturated density of 16 kN/m^3. Both the clay balls and clayey sand are materials determined to settle rapidly; therefore, the required spacing between inlets is considered to be short relative to that of slowly settling soils. With soils that settle rapidly, inlet spacing must be a balance between what is needed to produce a level top surface and the loss in construction productivity and time that would result from changing the discharge line between many closely spaced inlets during filling.

Pilarczyk (1995) cites a distance of 75 m between inlets on a geotube®, and Fowler[1] describes field situations in which slurries of fibrous organic soil were pumped into geotubes® where the inlets were spaced as much as 150 m apart. This range may be reasonable distances between inlets for slurries of slowly settling, fine-grained clays.

---

[1] Personal Communication, Oct. 1996, Jack Fowler, Consultant to Nicolan Corporation.

3 ASTM Standard Test Methods for Geotextiles

Standard Procedures for Evaluating Geotextiles

In response to the developing market for geotextiles and their potential to provide solutions to difficult construction and material dewatering problems, numerous vendors supply many varieties of geosynthetic fabrics or geotextiles. The use of geotextiles has, in fact, risen steadily in the United States since about 1977. Geosynthetics, in general, and geotextiles, in particular, have come into such widespread use that the American Society for Testing and Materials (ASTM) has established Committee D-35 to standardize testing techniques and procedures for determining various properties of geotextiles within the industry. ASTM standard tests are useful in evaluating various properties of geotextiles since they allow meaningful comparison of one geotextile with another and ensure a uniform level of quality. Therefore properties determined from ASTM standard tests are used in the specifications of geotextiles to assure various qualities necessary for specific applications.

Tests to Determine Physical Properties

Several ASTM standard test methods are used to evaluate geotextile characteristics and properties that may serve as the basis for selecting one geotextile over another. These properties are:

1. Weight or density.

2. Thickness.

3. Stress-strain-strength characteristics.

4. Tearing resistance.

5. Puncture resistance.

6. Bursting resistance.

7. Opening size.

8. Resistance to degradation by ultraviolet light.

9. Water flow characteristics (permittivity).

The ASTM standard test methods used to determine the physical properties listed above (by number) are:

1. ASTM D 5261-92, Standard Test Method for Measuring Mass per Unit Area of Geotextiles, ASTM D 3776-85, Standard Test Method for Mass Per Unit Area (Weight) of Woven Fabric, and ASTM D 5199-91, Standard Test Method for Measuring Nominal Thickness of Geotextiles and Geomembranes.

2. ASTM D 1777-64 (Reapproved 1975), Standard Test Method for Measuring Thickness of Textile Materials.

3. ASTM D 4632-91, Standard Test Method for Breaking Load and Elongation of Geotextiles (Grab Bag), and ASTM D 4595-86, Standard Test Method for Tensile Properties of Geotextiles by the Wide-Width Strip Method.

4. ASTM D 4533-91, Standard Test Method for Trapezoidal Tearing Strength of Geotextiles.

5. ASTM D 4833-88, Standard Test Method for Index Puncture Resistance of Geotextiles, Geomembranes, and Related Products.

6. ASTM D 3786-87, Standard Test Method for Hydraulic Bursting Strength of Knitted Goods and Nonwoven Fabrics--Diaphragm Bursting Strength Tester Method.

7. ASTM D 4751-95, Standard Test Method for Determination of Apparent Opening Size of a Geotextile.

8. ASTM D 4355-92, Standard Test Method for Deterioration of Geotextiles from Exposure to Ultraviolet Light and Water (Xenon-Arc Type Apparatus).

9. ASTM D 4491-92, Standard Test Method for Water Permeability of Geotextiles by Permittivity.

These ASTM test methods can be found in their entirety in one or more of the annual volumes of ASTM standards (see References). However, these standard test methods (and some alternative ASTM test methods where applicable) are briefly described and summarized in Appendix A.

4 Design of Long Geotextile Tubes

Construction of Geotextile Tubes (Geotubes®)

Geosynthetic sheets may be sewn together to form a shell that is capable of confining pressurized slurry. A shell configuration of great practical significance and one that has been used to considerable advantage is that of a long cylindrical tube, that is, the geotube®. Slurry, in the context of this work, is a high-water-content, low-strength soil that is sufficiently fluid that it can be hydraulically pumped to fill the tube. Soil/water mixtures are technically "liquid" or "fluid" when their water content is greater than the liquid limit as defined by Casagrande (1948) and standardized in ASTM D 4318-95 (1995), "Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils." Slurries, as used in the context of this work, typically have water contents that are two to ten times the liquid limit.

After a geosynthetic tube/shell is filled with slurry, the system serves as a filter in that the geosynthetic/geotextile shell allows water to seep out of the interior while retaining the soil particles. With time, the processes of sedimentation and consolidation allow sufficient water removal from the soil (as the result of seepage through the pervious shell/tube) that the soil retained in the tube becomes solid. Consequently, this operation allows soils with high water content and low strength to become suitable construction materials. Without the confinement and filtration/drainage provided by the geosynthetic, such soils would not only be useless as construction material, but might represent a hazard or obstruction to the extent that they would require removal and placement in less objectionable locations. Reasons to remove such soils are (1) they are contaminated with chemicals and/or organic material and represent a danger to humans and the environment, (2) they interfere with productive activities, such as shipping, navigation, and recreation, or (3) some combination of (1) and (2).

By confining slurrified soils in long geotextile tubes and allowing them to dewater, it is possible to use them for construction of dikes, embankments, and other soil structures. However, because the soil slurry is initially a fluid, the encapsulating geotextile tube must be designed to withstand internal fluid pressure. A procedure for designing geosynthetic tubes to contain pressurized slurry is described by Leshchinsky and Leshchinsky (1996) and Leshchinsky et al. (1996). The design

procedure is based on the theory of thin shells, the assumption of plane strain, and the satisfaction of force equilibrium. The design procedure is presented as an interactive computer code, "GeoCoPS."

GeoCoPS

Methodology for designing long geosynthetic tubes to contain soil slurry is presented in a public-domain computer code called GeoCoPS (Geosynthetic Confined Pressurized Slurry) that was developed for the present CPAR investigation by Leshchinsky and Leshchinsky (1996). Version 1.0 of GeoCoPS is designed for use on International Business Machines (IBM™) compatible or clone digital computers with at least 2MB RAM and an Intel™ 386 processor or higher. The code is designed to be run in an MS-DOS™ environment with DOS 4.00 or higher. At this writing, a Microsoft Windows™ version of the code has not been prepared.

GeoCoPS is available to users directly from the World Wide Web at the address:

www.wes.army.mil/gl/software.html

(Users must be aware that all alpha characters in this address are lower case, as indicated).

GeoCoPS is user friendly in that it guides a designer to input known parameters, then prompts the user to choose the appropriate ensuing analytical procedure from a menu. The code then computes and tabulates unknown components of the design and, as an option, will construct and print a drawing of the design configuration. Design from three options are supported by GeoCoPS:

1. The ultimate strength of the geosynthetic is provided by the designer to find the geometry of the tube.

2. The design height of the tube is provided by the designer to find the maximum tension within the geosynthetic shell.

3. The pumping pressure (gage pressure at the top of the tube when the tube has reached its design height) is provided by the designer to find the geometry of the tube and the maximum tension within the geosynthetic shell.

A designer is allowed to specify the density of slurries acting in the tube/ slurry configuration; two layers of slurry, each with a different density,[1] may be placed inside and/or outside the tube in options 1 and 2 above. In option 3, only a single slurry with a uniform density may be placed inside and/or outside the geosynthetic tube.

---

[1] The layer of slurry with the highest density will, of course, be placed at the bottom of the configuration whether it be inside or outside of the geotextile tube.

In addition to being user friendly, GeoCoPS has several unique and useful attributes, including the feature that anisotropy of the geosynthetic is taken into account. Geosynthetics in general and geotextiles in particular are anisotropic, meaning that strength in the machine direction (corresponding to the circumferential direction of the tube) is different from that in the cross direction (corresponding to the axial direction of the tube). The discrepancy in strength between the machine and cross directions is great enough to result in strength deficiency in some geotextiles. GeoCoPS computes and reports strength requirements in the longitudinal/cross direction so that a designer may check that sufficient strength is provided by the geotextile selected.

Another useful feature of GeoCoPS is that it allows the application of partial safety factors for any of several areas of uncertainty that may affect the ultimate performance of the tube. The areas of uncertainty and the recommended minimal safety factors are discussed below.

Minimal Safety Factors for GeoCoPS

GeoCoPS allows application and adjustment of safety factors for uncertain behavior and performance in the following areas:

a. Installation damage, referring to accidental over-pressurization during initial filling and pressurizing the tube. A preliminary minimal safety factor of 1.3 is recommended for installation damage.

b. Seam strength, because the strength of a sewn seam is invariably lower than that of the clear woven geotextile. Sprague and Fowler (1994) state, "The seam strength is normally the weakest link in the design and depending on the seaming technique specified this value may be only half of the fabric ultimate strength." One possible explanation for reduced seam strength is that a (hand held) sewing machine used to stitch field seams breaks yarn and otherwise damages the fabric. Additionally, a sewn seam is never entirely aligned properly with the grain of the woven geotextile; therefore as load is applied to the seam, stress concentrations occur in some of the fibers to result in premature breakage. Broken fibers caused by the act of sewing and by stress concentrations due to the presence of the seam result in lower strength. Based on experience gained from laboratory measurement of the strength of sewn seams, a preliminary minimal safety factor of 2.0 is recommended.

c. Chemical degradation, which includes damage that results from ultraviolet (UV) radiation exposure as well as exposure to chemical agents. A minimal safety factor of 1.0 is recommended for chemical and ultraviolet radiation damage because most geosynthetics are inert and highly resistant to chemical damage. Additionally, many geosynthetics contain carbon black to make them resistant to UV damage. As the result of the inert character of many geosynthetics and the fact they are manufactured with protective additives, most geosynthetics deteriorate slowly when exposed to UV radiation.

d. Biological degradation does not appear to be critical in most applications since biological activity is generally a long-term concern, whereas filtration of solids occurs in a few weeks to a few months after installation. Recommended minimal safety factor is 1.0.

e. Creep is deformation that occurs under a constant load in susceptible materials. In allowing for creep, maximum sustained loads are decreased so that deformation at the end of the design life of a geosynthetic structure can be tolerable. Creep in geosynthetics can be determined using ASTM D 5262-95, "Standard Test Method for Evaluating the Unconfined Tensile Creep Behavior of Geosynthetics." Maximum tensile force in a geosynthetic tube is developed immediately after the tube has been pumped full during installation; as time increases and water is discharged, the slurry solidifies and the maximum tensile force in the geosynthetic decreases as excess pore water pressure within the tube dissipates. Therefore, since the maximum force is applied for only a short time relative to the design life of a geosynthetic tube, an appropriately small creep safety factor can be assigned. However, the factor must be sufficient that tensile creep rupture does not occur during the period immediately following filling when tensile stress is maximum. Tensile creep rupture strength is the force per unit width (obtained from ASTM D 5262-95) that produces failure by creep in a laboratory creep test in a given time period under specified constant environmental conditions. Unless otherwise stipulated, creep tests are conducted (as directed by ASTM D 5262-95) under environmental conditions of air temperature at $21 \pm 2°C$ ($70 \pm 4°F$) and relative humidity between 50 and 70 percent. It is to be noted that laboratory-performed creep tests yield results that are generally conservative. The creep of a given geosynthetic is likely reduced in service because of load transfer to the soil. A minimum preliminary safety factor of 1.5 is recommended for creep.

As stated, the safety factors recommended above are minimal values and may be used in general cases where specific information is not available. They are the default values programmed into GeoCoPS and may be changed as conditions for specific field cases demand, and as better information is available.

Soil Retention

One of the important functions performed by geotextiles is filtration. During filtration, water in an encapsulated soil seeps through the manufactured plane of the geotextile driven by the forces of gravity and soil self-weight while the solid particles are retained. As water flows out of the soil-water mixture by seepage, there is a tendency for soil particles to be carried out with the water and the tendency increases as seepage velocity increases. However, the escape of solids through the geotextile must be limited and controlled because the soil particles themselves, or compounds adsorbed onto their surfaces, may be environmentally unsuitable.

Using a geotextile to retain solid particles while allowing water to escape requires a certain compatibility between the sizes of soil particles and the sizes of

openings through the geotextile. The apparent opening size (AOS) of the geotextile may be determined using ASTM D 4751-95, "Standard Test Method for Determination of Apparent Opening Size of Geotextiles." Based on the AOS, the method recommended to assure the retention of soils having a particular grain-size distribution is that developed by Task Force No. 25, American Association of State Highway and Transportation Officials (AASHTO 1990). The recommended method is:

a. For soil with 50 percent or less particles by weight passing the U.S. No. 200 sieve, the O_{95} of the geotextile must be less than 0.595 mm (AOS greater than No. 30 U.S. Standard Sieve).[1]

b. For soil with more than 50 percent particles by weight passing the U.S. No. 200 sieve, the O_{95} of the geotextile must be less than 0.297 mm (AOS greater than No. 50 U.S. Standard Sieve.

Leshchinsky (1992) reports that when the soil being filtered by a geotextile is a slurry containing clay, experience shows that the escape of particles through the geotextile stops rapidly and the seepage water becomes clear. Data acquired during the present investigation are presented later to show how soil-particle escape through a geotextile decreases with time.

However, a geotextile system serves only to prevent the escape of soil particles. If soluble contaminants are present in the water, then additional steps must be taken. Dissolved chemicals are disbursed in water at the molecular level and are of molecular size. Therefore, dissolved matter moves with the water and the mass transport of such chemicals (through a geotextile) is unaffected by time and its removal cannot, as yet, be achieved with geotextiles.

It is important that a geotextile system retain solid particles to the maximum extent possible, but it is unrealistic to expect that complete solids retention will be achieved. Model experiments were conducted in a concrete-lined sump filled with clear water to investigate the effectiveness of geotextile systems in containing soil particles while allowing water to be expelled. Studies were conducted using a model bottom-dump scow to simulate clay slurry placement in deep water by dropping a dredge-material-filled geocontainer® from the model scow. The studies showed that although a small amount of material was observed to be released upon striking the bottom of the sump, the layered geotextile system was extremely effective in containing the vast majority of soil solids.

Clogging

Clogging potential in geotextiles is defined in ASTM D 5101-90 (1995) as the tendency for permeability decrease due to soil particles either lodging in the

---

[1] O_{95} is the 95 percent opening size of the geotextile that is the equivalent in millimeters to the AOS as defined in ASTM D 4751-95 (1996).

openings or building up a restrictive layer on the surface of the geotextile. The testing procedure involves setting up a geotextile and soil in a permeameter and subjecting the system to different flow rates and hydraulic gradients. The procedure is intended to evaluate geotextile performance with site-specific soils. Permeability in the field decreases somewhat due to the buildup with time of a layer of soil with lower permeability on the inside of a geotextile. However, clogging should not be a problem if the geotextile was chosen on the basis of the AASHTO (1990) AOS criteria described above.

Geotube® Height Change

Because of the low solids content of slurries generally used to fill geotubes®, the decrease in height as the result of water expulsion and consolidation is significant, although experience shows that the width of a tube changes very little as water is expelled during consolidation. Leshchinsky and Leshchinsky (1996) and Leshchinsky et al. (1996) give the expression

$$\frac{\Delta h}{h_o} = \frac{G_s(\omega_o - \omega_f)}{1 + \omega_o G_s} \tag{1}$$

where

Δh = decrease in height of the tube

h_o = initial height of the tube

G_s = specific gravity of soil solids

ω_o, ω_f = initial and final water contents, respectively, of the slurry

Equation 1 yields the fractional decrease in height ($\Delta h/h_o$) of the tube as a function of the change in water content of the slurry. Obviously as water is expelled, the average water content of the slurry decreases and tube height decreases as indicated by Equation 1. Leshchinsky (1992) presents evidence that tubes filled with typical slurry may decrease in height by about 50 percent when they are allowed to drain freely in air under the action of gravity. In about a month, the solidified material in the tube is generally dense and solid enough to support the weight of a man standing on it. Sprague and Fowler (1994) also report that geotubes® filled at Gaillard Island in Mobile, AL, decreased about 50 percent in height in about four to six weeks, at which time they were refilled.

If a specific tube design height is required, then multiple fillings and periods for consolidation/subsidence are necessary and must be planned in terms of the filling operations and consolidation time. Each filling results in the loss of about 50 percent of the current fill height because of water expulsion and the resulting soil consolidation.

Internal Pressure Control for Design and Construction

In a parametric study of the relationships among internal pressure, geometry, and fiber tensile stress, Leshchinsky et al. (1996) use GeoCoPS to investigate design requirements and how they may best be achieved. Two requirements may be satisfied in designs using geotextile tubes:

a. A requirement in which a given tube height is needed to provide specific volume storage in an area enclosed by a geotextile tube.

b. A requirement in which a given tube cross-sectional area is needed to provide specific volume storage within a geotextile tube.

The theoretical maximum cross-sectional area and height of a tube with a given circumference is that of a circular section (Leshchinsky et al. 1996). However, the theoretical maximum cannot be achieved, since infinite internal fluid pressure (and therefore infinite strength in the geotextile shell) is required to produce a circular cross section. During filling, pressure in the fluid at the top of the tube (called pumping pressure) generally remains at zero gage until the tube reaches about one third of its theoretical maximum height. From this point, the height and cross-sectional area increase steadily as additional fluid is injected into the tube with steadily increasing pumping pressure. However, the tube soon reaches a point where additional pump pressure produces little increase in height or cross-sectional area, but substantial increases in fiber stress. In fact, the theoretical maximum height and cross-sectional area can only be approached asymptotically as internal pressure is increased without limit.

Typical behavior of a geotextile tube system with internal pressure applied is illustrated here using tubes that are 30 and 80 ft in circumference. The tubes under analysis are free standing in air (meaning not submerged in water) and filled with fluid that is 1.3 times the density of water. Figures 1, 2, and 3 are used to illustrate typical tube behavior predicted by GeoCoPS.

Figure 1 shows the relationship between pumping pressure and percent of theoretical maximum tube height; the asymptotic behavior between maximum height and pumping pressure is demonstrated in the figure. Points of maximum curvature occur at about 80 percent maximum height and 4-psi internal pressure for the 30-ft circumference tube, and about 70 percent maximum height and 4-psi internal pressure for the 80-ft circumference tube. These points of maximum curvature are chosen as practical limits between the initial portion of the curves that rise sharply and the asymptotes that are relatively flat. Figure 2 shows the relationship between fiber tension and pumping pressure. As seen in Figure 2, applied internal pressures of 4 psi in the 30-ft and 80-ft circumference geotubes® produce tensile fiber stresses of about 300 and 1000 pli[1] (pounds per linear inch), respectively. Further,

[1] GeoCoPS determines the maximum fiber tension required for the set of conditions prescribed. The geotextile chosen by the designer for the duty must provide the necessary strength.

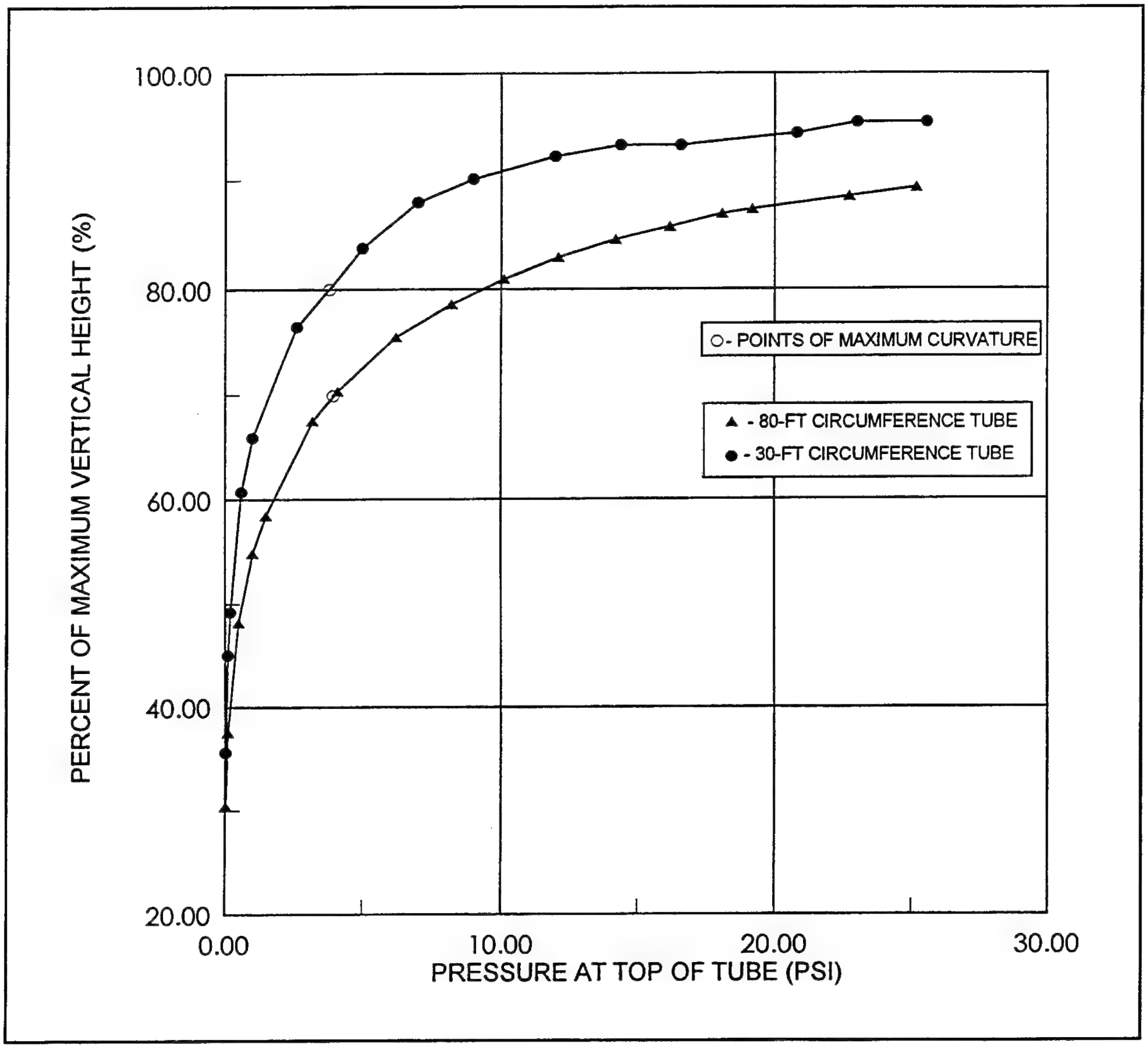


Figure 1. Percent height increase with pumping pressure

Figure 1 shows that after the asymptotic portions of the curves are reached, internal pressure may be increased substantially with little additional increase in tube height.

Figure 3 shows an asymptotic relationship between percent maximum theoretical cross-sectional area and pumping pressure similar to that between maximum theoretical height and pumping pressure. Again, the asymptotic portions of the curves begin after the points of maximum curvature, which occurs at about 95 percent of maximum area at 4 psi for the 30-ft circumference tube and about 90 percent maximum area and 4 psi for the 80-ft circumference tube. Figure 3 demonstrates that relatively little additional storage (in terms of cross-sectional area) is produced by additional pressure. However, fiber stress is seen (in Figure 2) to increase linearly as internal tube pressure is increased.

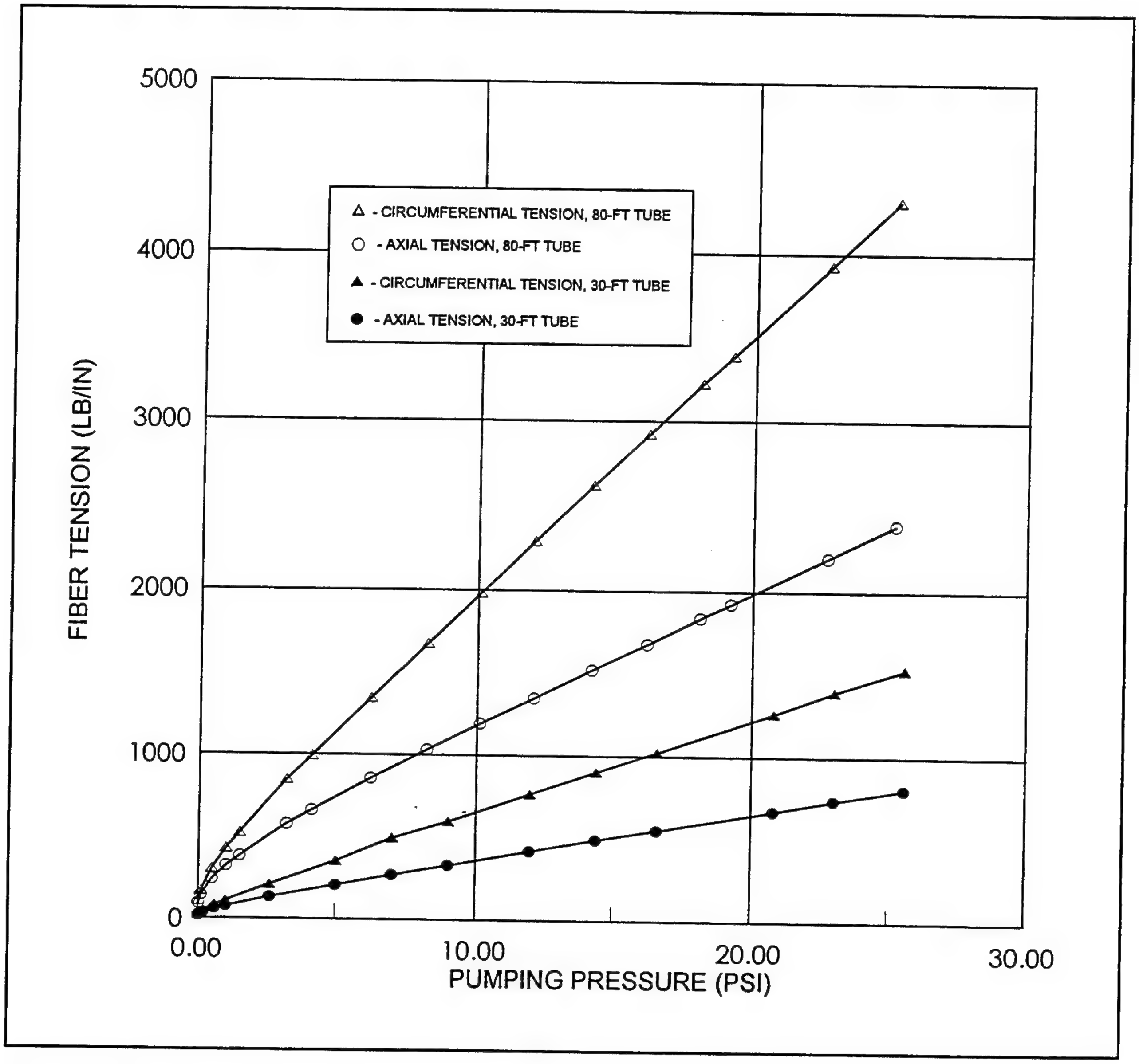


Figure 2. Fiber tension versus pumping pressure

The implication of these two examples is that a design height or cross-sectional area for achieving required storage may be determined using GeoCoPS. However, if the target design is on or near the asymptotic portion of the curve, it is necessary to control flow into the tube very carefully during construction, because slight overfilling in this asymptotic region can cause rapid increase in fiber stress. If this response is not appreciated and anticipated during construction, overfilling and the associated rapid increase in internal pressure may cause sudden rupture of a geotextile tube. Conversely, if the target design is below the asymptotic portion of the curves, then the geotextile tube is more "forgiving" of slight overfilling. However, it must be realized that a greater circumference of geotextile (and consequently a less economical design) is required if it is desired to work below the asymptotic portion of the curves where overfilling may be better tolerated.

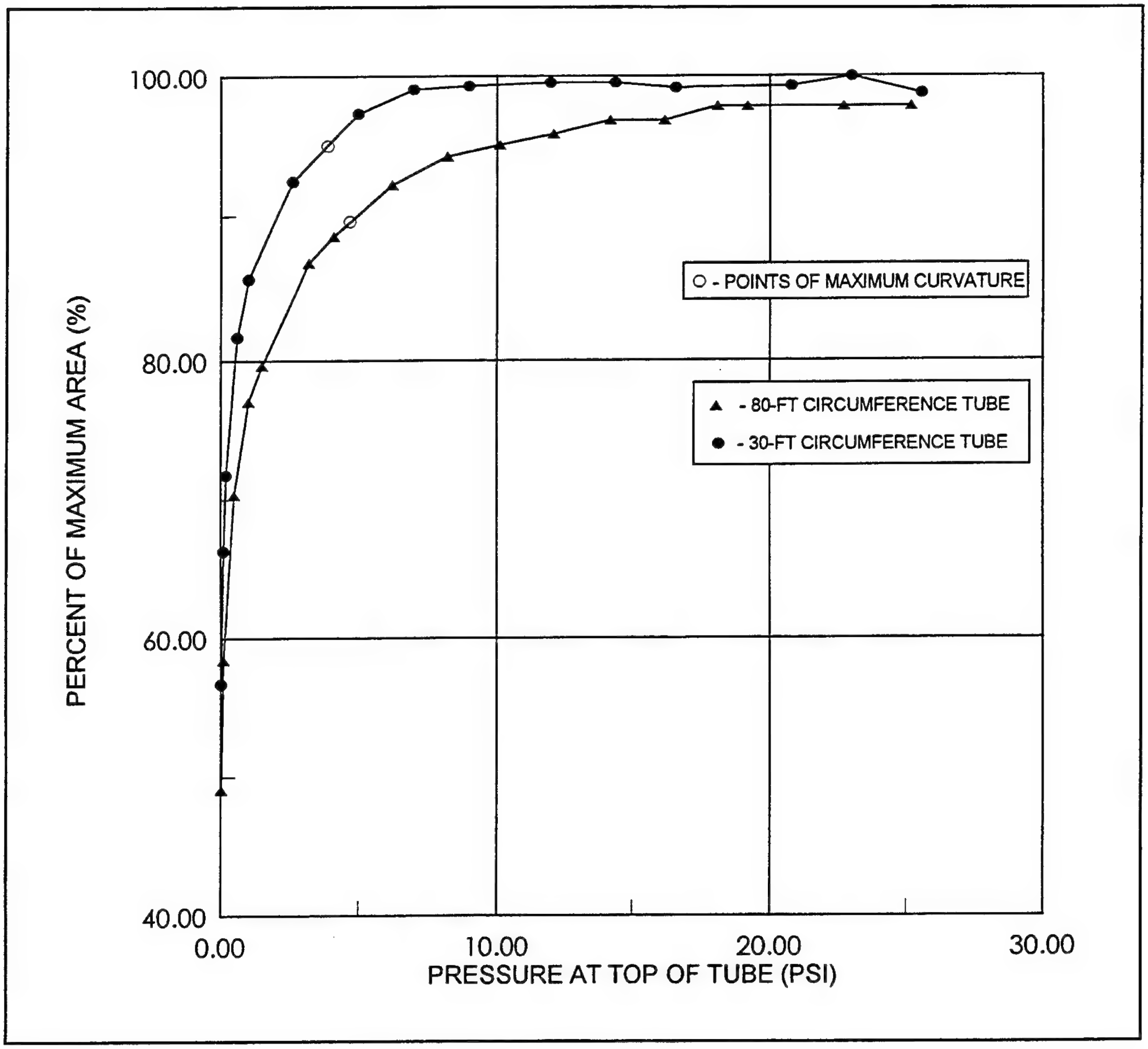


Figure 3. Percent area increase with pumping pressure

Pilarczyk (1995) states that a tube achieves its desired shape when filled up to about 80 percent of its theoretical maximum height based on methods provided by Delft Hydraulics Laboratory (1973), Silvester (1986), and Bogossian et al. (1982). GeoCoPS confirms that this is, in fact, true; examination of Figures 1 and 3 shows that if the example tubes are filled to 80 percent of their maximum theoretical heights, about 90 to 95 percent of the maximum theoretical area in each tube is mobilized. However, it may be worthwhile to mention that the position of 95 percent maximum theoretical area is near (for the 30-ft circumference tube) or beyond (for the 80-ft circumference tube) the point of maximum curvature where the asymptotic portion of the curve begins (see Figure 3). Therefore, filling beyond this point causes rapid increase in internal pressure, fiber tension, and the danger of geotube® rupture.

Hence, if the size of a tube to be constructed allows, and a geotextile of sufficient strength is available, it may be reasonable to choose a filling height near, but less than, 80 percent of the maximum theoretical height as a desirable target for design. This allows efficient use of available storage, yet avoids the asymptotic areas where precise flow control during construction is required. Pilarczyk (1995) states, additionally, that filling beyond 80 percent reduces friction between tubes, and may cause instability problems if tubes are stacked.

If it is necessary to work on or near the asymptotic portion of the curves as described above, and if the configuration of a field construction site is such that pump flow cannot be controlled precisely, then it is necessary to use other measures to control flow into and, therefore, pressure inside the geotextile tube. One such measure is to use an overflow tube for pressure control. In such an arrangement, a simple open standpipe is placed in line near the inlet port where fluid is introduced into the tube. The standpipe must be positioned such that it has height, H_s, above the top of the geotube®. If it is determined that an internal pressure, P_i, at the top of the tube must never be exceeded, then the height, H_s, is given by

$$H_s = \frac{P_i}{\gamma_f} \tag{2}$$

where

γ_f = density of the fluid being pumped into the geotube®.

Sprague and Fowler (1994) state that a maximum filling pressure in geotubes® at the inlet point has been observed to be about one third of an atmosphere, approximately 5 psi. Examination of Figures 1, 2, and 3 shows this to be a reasonable pumping pressure for geotubes® less than 30 ft in circumference that are filled free standing in air. For example, Figures 1 and 2 show that 5-psi pumping pressure produces a circumferential tension of 350 pli[1] in the geotextile shell and about 84 percent of the maximum theoretical height. However, when pumped to an internal pressure of 5 psi, the 80-ft circumference tube develops a circumferential tension of 1150 pli.

Summary

GeoCoPS is a user friendly computer code that may be used to design geotextile tubes for the provision of a given design height or cross-sectional area while limiting the stress in the geotextile fibers to safe levels. Fiber stress is controlled by applying safety factors that take into account installation damage, seam strength, chemical degradation, biological degradation, and creep.

---

[1] Density of the filling fluid is 1.3 times that of water in this example. However, even if the filling fluid had been water, the resulting fiber tension in the circumferential direction would be 330 pli.

During filling, geotextile tubes develop little internal pressure until they reach about one third of their design height and about two thirds of their design cross-sectional area. When internal pressure begins to develop, it is important to monitor the pressure in the tube carefully, since internal pressure can increase quickly to result in the geotextile fibers being overstressed. The design pumping pressure is determined using GeoCoPS, and it is crucially important to control volume flow into the tube and not exceed the design pump pressure during filling. Exceeding the design pressure results in negligible increase in tube height and volume storage, but substantially increases the risk of rupturing the tube.

5 Geotextiles Used in Investigation

Four geotextiles manufactured by the Nicolon Corporation were used in this investigation: Nicolon S1200, GT 500, HP570, and GT 1000. They will be briefly described with respect to properties determined by ASTM standard tests.

Nicolon S1200

Nicolon S1200 is a polypropylene nonwoven needle-punched geotextile. Properties determined from ASTM standard tests performed by the Nicolon Corporation are listed in Table 3.

Table 3
ASTM Properties of Nicolon S1200 Nonwoven Geotextile

Fabric Property	ASTM Test Method	Units	Minimum Average Roll Value
Fabric weight	D-5261	oz/yd^2	12.0
Thickness	D-5199	mils	145
Grab tensile strength	D-4632	lb/in.	350
Grab tensile elongation	D-4632	percent	60
Trapezoid tear strength	D-4533	lb	125
Puncture resistance	D-4833	lb	190
Mullen burst pressure	D-3786	psi	650
Water flow rate	D-4491	gpm/ft^2	60
Permeability	D-4491	cm/sec	0.33
Permittivity	D-4491	sec^{-1}	0.751
UV resistance	D-4355	percent	70
Apparent opening size (AOS)	D-4751	U.S. Sieve, mm	100 (0.150)

Nicolon S1200 served as a liner in geotextile systems used in this investigation where filtration was required to prevent the escape of small soil particles through the manufactured plane. The material is stable in a pH environment ranging from 2 to 13, is resistant to commonly encountered soil chemicals, and is nonbiodegradable.

Nicolon GT 500

Nicolon GT 500 is a polypropylene woven monofilament geotextile. Properties determined from ASTM standard tests performed by the Nicolon Corporation are listed in Table 4.

Table 4
ASTM Properties of Nicolon GT 500 Woven Geotextile

Fabric Property	ASTM Test Method	Units	Minimum Average
Grab tensile strength	D-4632	lb/in.	600 X 700[1]
Puncture resistance	D-4833	lb	300
Trapezoid tear strength	D-4533	lb	200 X 300
Mullen burst pressure	D-3786	psi	1500
Wide width tensile strength	D-4595	lb/in.	400 X 550
Wide width tensile elongation	D-4595	percent	15 X 15
AOS	D-4751	U.S. Sieve No.	60
Permeability	D-4491	cm/sec	0.02
Seam strength	D-4595	lb/in.	350

[1] Values are given in the machine direction X cross direction.

Nicolon HP570

Nicolon HP570 is a polypropylene woven monofilament geotextile. Properties determined from ASTM standard tests performed by the Nicolon Corporation are listed in Table 5.

Nicolon GT 1000

Nicolon GT 1000 is a polyester woven geotextile. Properties determined from ASTM standard tests performed by the Nicolon Corporation are listed in Table 6.

Table 5
ASTM Properties of Nicolon HP570 Woven Geotextile

Fabric Property	ASTM Test Method	Units	Minimum Average
Grab tensile strength	D-4632	lb/in.	415 X 410[1]
Grab tensile elongation	D-4632	percent	12 X 8
Puncture resistance	D-4833	lb	160
Trapezoid tear strength	D-4533	lb	180 X 180
Mullen burst pressure	D-3786	psi	1200
AOS	D-4751	U.S. Sieve No.	30 (0.595 mm)
Permeability	D-4491	cm/sec	0.06
Permittivity	D-4491	sec^{-1}	0.4
Flow rate	D-4491	gpm/ft^2	30
UV resistance after 5000 hr	D-4355	percent strength	70

[1] Values are given in the machine direction X cross direction.

Table 6
ASTM Properties of Nicolon GT 1000 Woven Geotextile

Fabric Property	ASTM Test Method	Units	Minimum Average
Puncture resistance	D-4833	lb	400
Trapezoid tear strength	D-4533	lb	900 X 800
Wide width tensile strength	D-4595	lb/in.	1000 X 1000
Wide width tensile elongation	D-4595	percent	10 X 10
AOS	D-4751	U.S. Sieve No.	60
Seam strength	D-4595	lb/in.	500

Tensile Pull Versus Elongation Characteristics

Tests to investigate tensile pull-elongation characteristics were performed in accordance with ASTM D-4595 on Nicolon geotextiles GT 500 and GT 1000; results of these tests are shown in Figures 4 and 5, respectively. Figures 4 and 5 show that strength and stiffness are higher in the cross direction than in the machine direction for both geotextiles, although the differences are greater between the machine and cross directions in GT 500 than in GT 1000. These geotextiles were designed with higher strength and stiffness in the cross direction since they are intended specifically for the fabrication of geotubes® and geocontainers®.

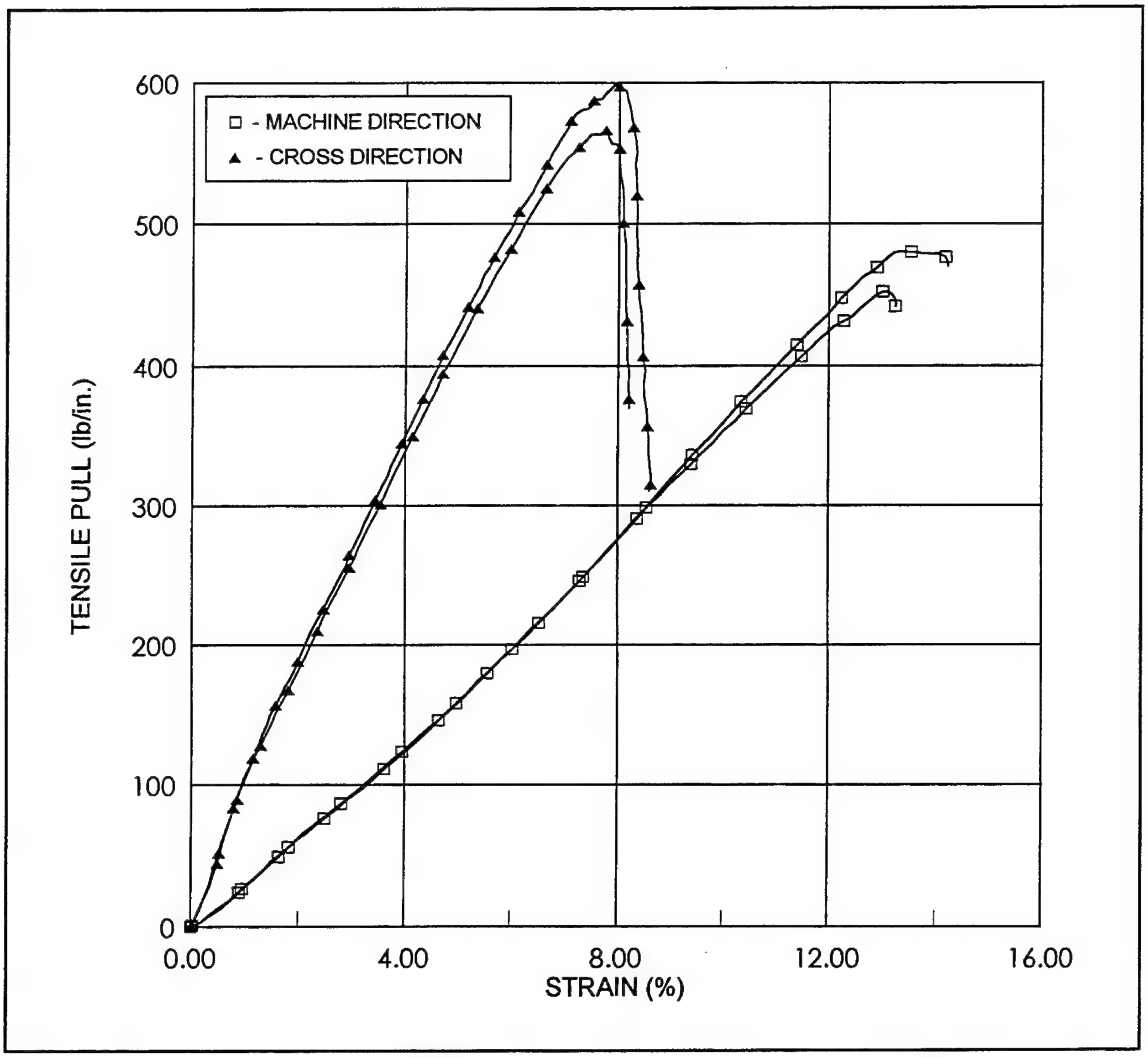


Figure 4. Tensile pull versus elongation strain for GT 500

Figure 6 shows typical tensile pull-elongation characteristics of Nicolon HP570. HP570 is a more balanced geotextile in terms of the approximately equal strength and stiffness in the machine and cross directions.

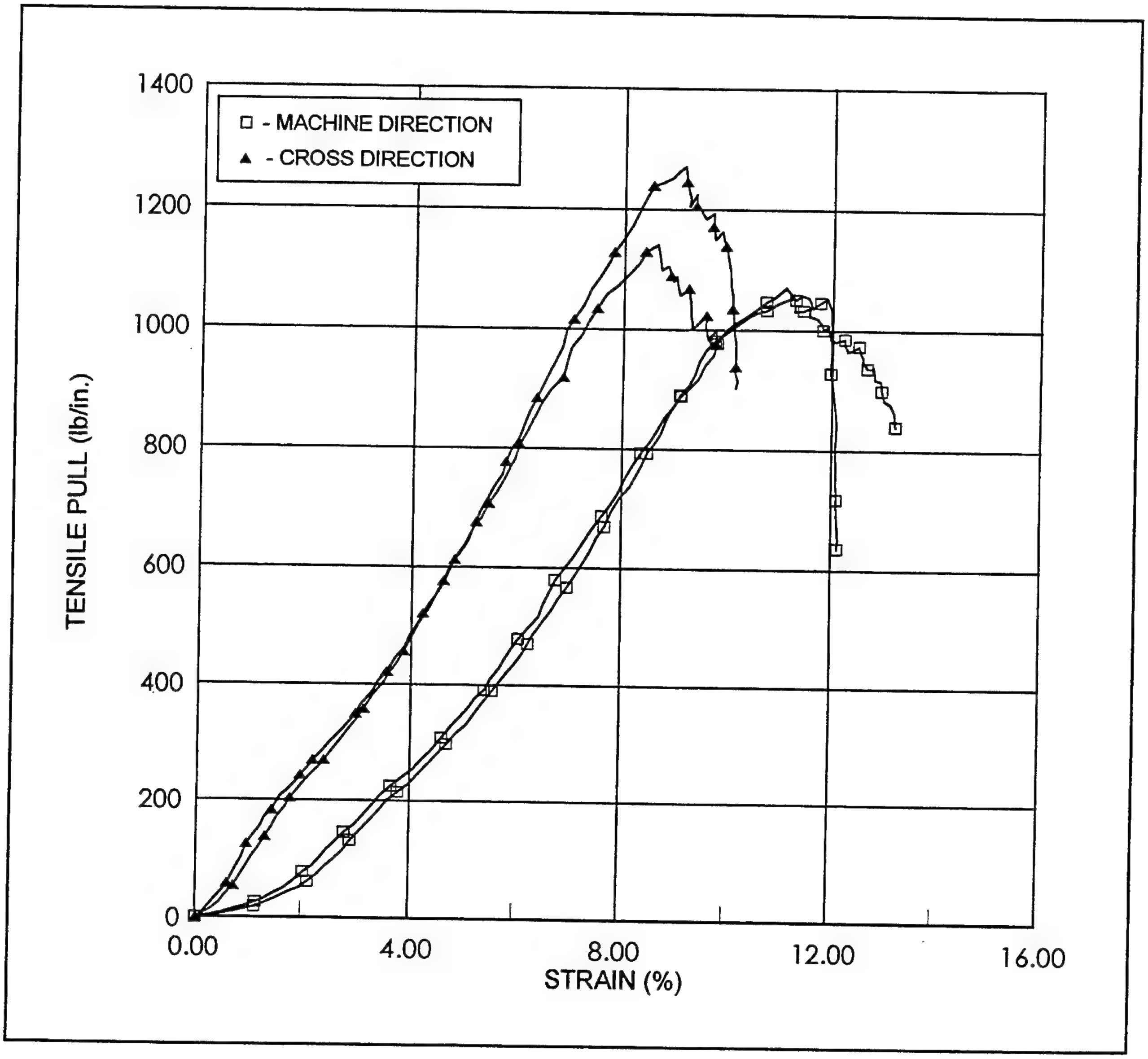


Figure 5. Tensile pull versus elongation strain for GT 1000

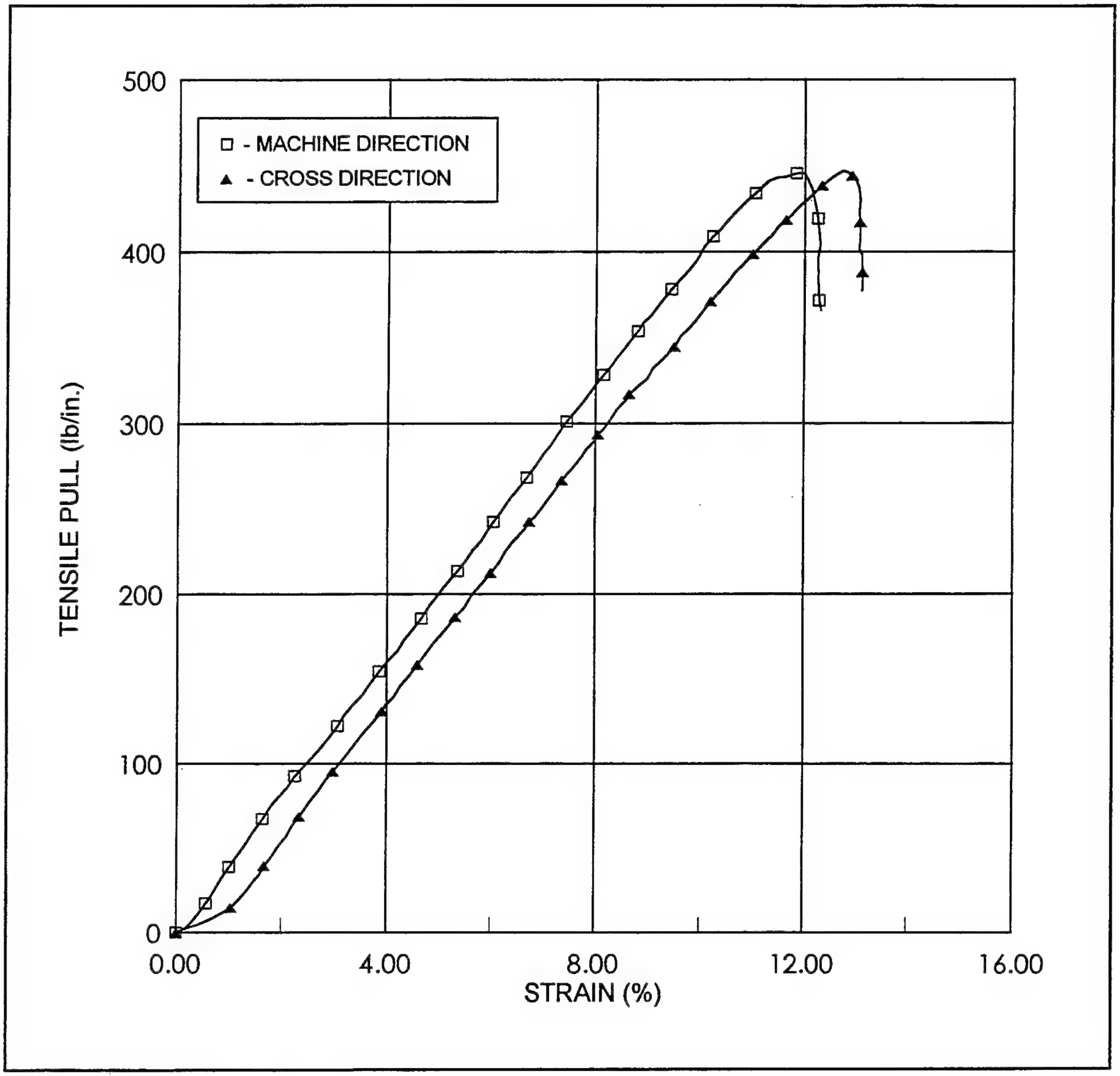


Figure 6. Tensile pull versus elongation strain for HP570

6 Use of Geotextiles in Dredging and Dredging-Related Construction

Construction of Enclosed Containment Facilities

Maintenance dredged material is soil that detaches from inland deposits and washes into streams and rivers as a result of erosion. This soil can accumulate in waterways to the extent that it ultimately interferes with productive activities. Maintenance dredged material has high water content and low strength and is sometimes contaminated with toxic chemicals. With continued accumulation it can interfere with ship traffic in navigation channels. If this happens, removal of the maintenance dredged material is necessary.

When maintenance dredged material is removed from its in situ location, an environmentally sound plan to store the material is essential if it cannot be returned to the water column because of environmental constraints. One technology for handling maintenance dredged material in an environmentally acceptable manner is to place it in an enclosed containment facility for dewatering and permanent storage. Containment facilities (i.e., diked enclosures) for storing maintenance dredged material may be constructed by enclosing an area with geotubes® filled with dewatered slurry.

Soft foundation conditions and the lack of good construction soil combine to make construction of containment facilities difficult and expensive in the coastal environment. Additionally, disturbance to the fragile coastal environment as the result of the numerous activities involved in bringing in suitable construction material from the outside may be unacceptable. In this sense, construction of dikes/embankments by encapsulating and dewatering slurry in geosynthetic/geotextile tubes may represent the best, and possibly the only, viable solution for constructing diked enclosures. Other techniques may be prohibitively expensive, difficult, and environmentally damaging.

The use of maintenance dredged material for construction of enclosed confinement facilities is extremely advantageous in the sense that the approach makes

productive use of what is essentially a waste material. Maintenance dredged material is in a liquid state as it is used to fill a geotextile tube; therefore, the public domain computer code GeoCoPS may be used to determine the initial geometry and strength requirements of the tube.

Geotextile Encapsulation for Deep-Water Placement

One of the significant advantages of geotextiles is that they may be sewn together to form products to perform custom functions. Containerization of dredged material for deep-water placement is one of the specialized uses of geotextiles. For example, a geotextile composite system that has been used for disposal/placement of dredged material consists of an outer shell of woven polyester fabric and a liner consisting of a continuous filament polyester nonwoven fabric. The purpose of the outer shell is to provide strength and abrasion resistance to a container constructed of the two geotextiles. The function of the inner liner is to provide filtration and prevent the escape of fine soil particles from the container.

Dual-sheet geotextile systems, like that described above, have been placed in hydrobarges or bottom-dump scows for containerization, transport, and placement of the dredged material. The procedure consists of:

Step 1. Lining the hopper of a bottom-dump scow with sheets of geotextiles that are sewn together.

Step 2. Placing dredged material in the geotextile-lined hopper. This operation may consist of mechanical or hydrodredging.

Step 3. Closing the container by placing and sewing a flap of the geotextile system over the top of the dredged material. If hydrodredging is used, this step consists only of closing the inlet ports through which the dredged material is introduced.

Step 4. Transporting the bottom-dump scow and containerized dredged material to a deep-water placement/disposal site.

Step 5. Placing the container and dredged material by dropping them from the bottom-dump scow.

Step 6. Covering the container and dredged material with a layer of clean (meaning uncontaminated) sand sufficiently thick to prevent the intrusion/invasion of plants and animals into the possibly contaminated dredged material.

Step 6 is necessary if the dredged material is contaminated with dangerous or toxic chemicals. If the dredged soil consists mainly of sand-sized particles, then the geotextile container can consist of only a single sheet to provide containment of the

soil. However, for dredged materials that contain substantial amounts of silt- and clay-sized particles, an inner liner may be required to provide filtration and containment, thus reducing the escape of fine particles into the water column.

7 Demonstrations of Geobags®, Geotubes®, and Geocontainers®

Several applications of geotextile soil encapsulation were demonstrated during the present investigation. Some of the more significant projects and findings are described and summarized below.

Nippersink Lake Filtration Tests

Nippersink Lake is located in northern Illinois about 20 miles west of Lake Michigan, 10 miles south of the Wisconsin state line, and 35 miles northwest of Chicago. It is one of a chain of shallow bog lakes forming the source of the Fox River which flows south to empty into the Illinois River. The bottom of Nippersink Lake is a peaty clay that contains volatile organic matter[1] measured to be between 17 and 24 percent by weight. Liquid limit of the Nippersink Lake soil is 192 and the plasticity index is 85; the material is classified OL according to the Unified Soil Classification System (USAEWES 1960). Specific gravity of the soil solids is 2.33 and a typical grain-size distribution is shown in Figure 7.

A filtration demonstration was performed on Nippersink Lake soil since plans are to enclose an area in the lake with a geotube® for storage of dredged material and wetland restoration. The filtration demonstration was conducted because verification and documentation of the quality of seepage water discharging from geotubes® are necessary. By Illinois Environmental Protection

[1] Volatile organic content (VOC) is the percentage of material by weight that is vaporized at 550 °C. Specifically it is computed from

$$\text{VOC} = \frac{(\text{Wt. soil dried at } 110\ ^\circ\text{C}) - (\text{Wt. soil dried at } 550\ ^\circ\text{C})}{\text{Wt. soil dried at } 110\ ^\circ\text{C}}$$

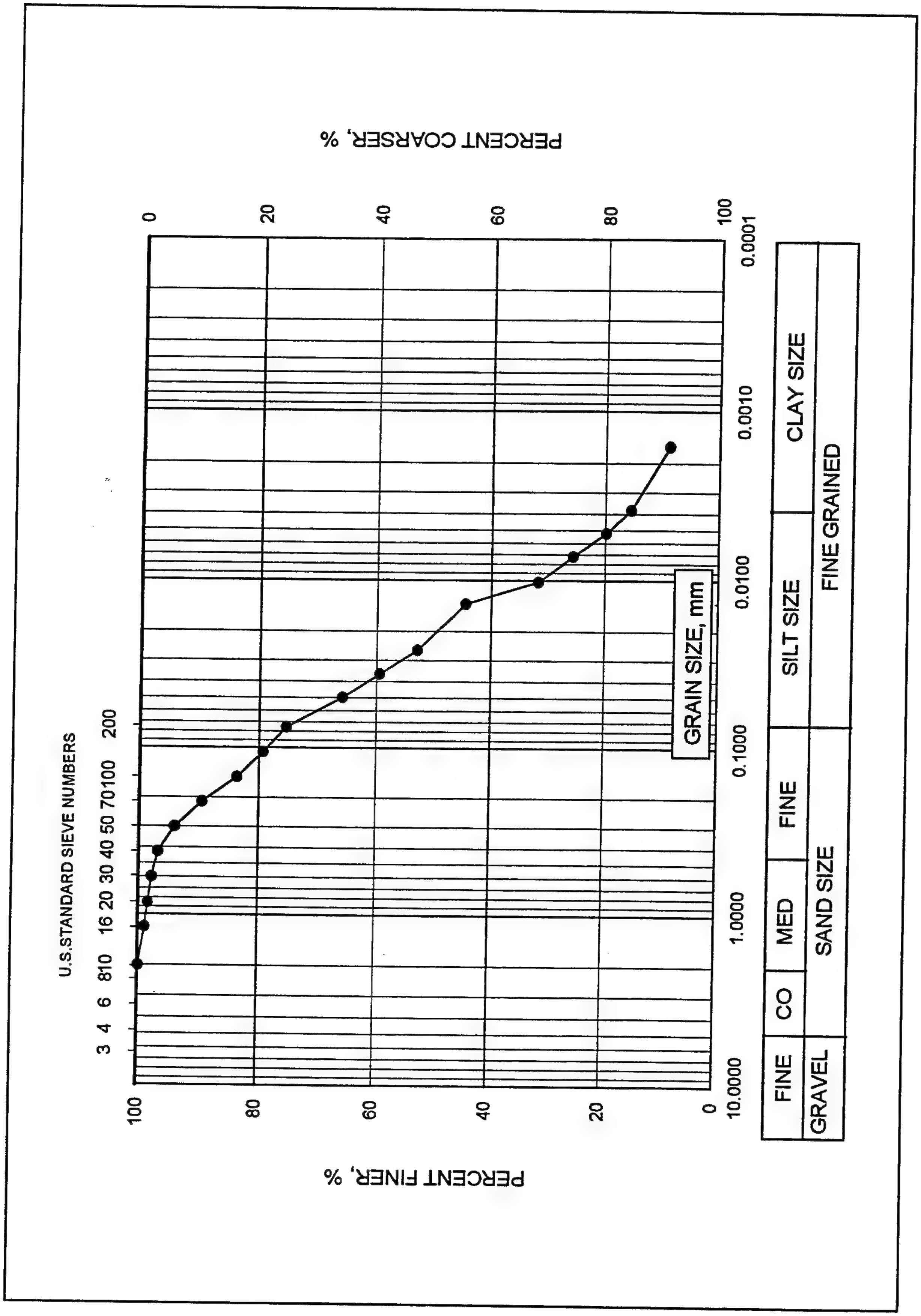


Figure 7. Grain-size distribution of Nippersink Lake soil

Agency (1993) regulation, if material is removed from a body of water by dredging, then water returned to the water column must contain no more than 15 parts per million (ppm) total suspended solids (TSS).

The filtration demonstration was conducted by filling a hanging bag with slurry and allowing water to seep out of the bag under the influence of gravity while sampling and testing the seepage water with the passage of time. Supported by a wooden frame, the hanging bag was about 36 in. in circumference, 60 in. long, and sewn closed at the bottom end. The geotextile system design was a composite, consisting of an outer layer of Nicolon GT 500 woven geotextile (for strength and abrasion resistance) and an inner liner of Nicolon S1200 nonwoven (for enhanced filtration). Properties of these two geotextiles are summarized in Tables 3 and 4.

A 10-in. hydraulic cutter-head dredge was used to pump the bag full of slurry with a solids content ranging between 3 and 6 percent solids by weight corresponding to water contents of about 3300 and 1700 percent, respectively. Water coming through the bag was sampled at several time intervals and various chemical and physical laboratory tests were performed. The test results are summarized in Table 7.

Table 7
Laboratory Tests on Nippersink Lake Seepage Water

Test For	Lake Background	Sampling Time Intervals		
		10 min	17 min	35 min
Ammonia (as N) ppm	0.80	20.75	19.17	18.33
pH	7.76	6.97	7.18	7.10
Total phosphorus ppm	0.37	0.18	0.17	0.17
Total suspended solids, ppm	196.0	8.8	7.3	2.1

Dissolved compounds such as ammonia, phosphates, and other chemicals affecting pH in the seepage water do not change appreciably with time, as can be seen from Table 7. The implication is that a geotextile system cannot remove or prevent the movement of chemicals dissolved in the water. However, soil solids suspended in the seepage water are observed to decrease substantially as time increases. This is believed to be the result of soil particles building up a restrictive layer on the inside of the geotextile system through which water must pass, thus further enhancing filtration characteristics. Although seepage water was not sampled immediately after filtration began, the total solids content at the beginning of seepage is judged to be at least twice that of the lake background. For illustration, the variation in total solids content of seepage water with time is presented in Figure 8 which shows that total suspended solids content decreases quickly when a geotextile system designed to prevent the escape of soil particles is used.

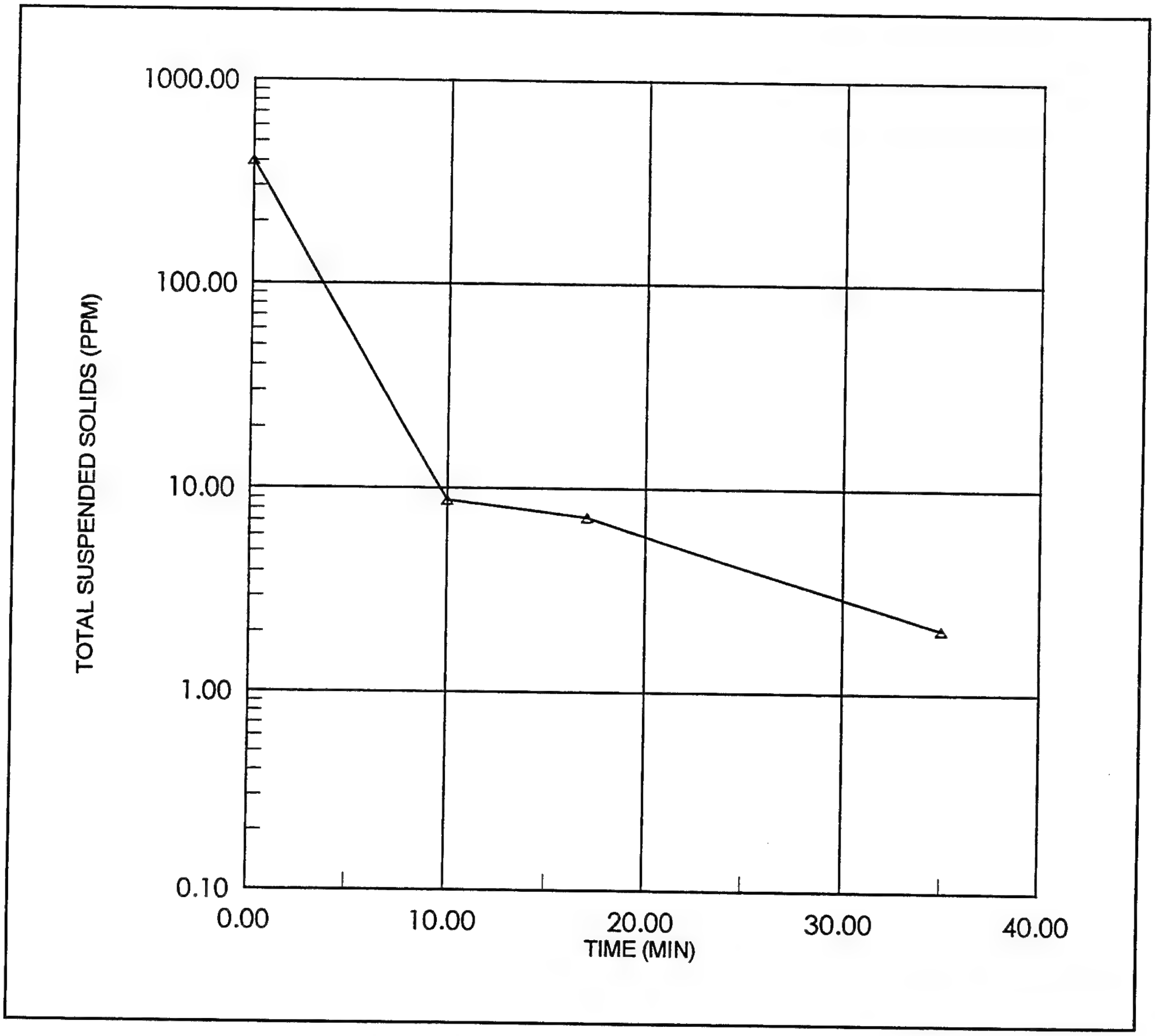


Figure 8. Decrease in total suspended solids with time

It should be pointed out that conditions for the Nippersink Lake demonstration were stringent in terms of seepage velocity and the tendency for soil solids to escape through the geotube®. Solids content of the slurry at Nippersink Lake was low (3 to 6 percent by weight). This produced high seepage velocity and therefore a greater tendency for soil solids to be carried through the geotube®. For comparison, a test was conducted in which a slurry with a solids content of about 30 percent was placed in a hanging bag identical to that used at Nippersink Lake. The comparison test slurry was placed in the bag at a water content of 215 percent (twice the liquid limit of the soil) with a density of about 1.2 g/cm^3. Clear water with a virtually undetectable solids content seeped through the geotube® from the beginning of the test, but at a substantially slower rate than that observed at Nippersink Lake. For example, seepage velocity may be indexed by the fact that at Nippersink Lake,

discharge of water from the bag stopped after about 24 hr. Conversely, water continued to flow from the demonstration test bag after 10 days.

During typical field construction, slurry is generally pumped at higher solids content than that used in the Nippersink Lake demonstration. For example, pumped slurry with a consistency more likely to be used during actual geotube® construction may have a density of 1.15 to 1.20 g/cm^3 and a solids content of about 25 to 30 percent by weight if the soil solids have a specific gravity of 2.33. Therefore, seepage velocity through the geotube® is lower and so is the tendency for the escape of soil particles.

At the opposite extreme, observations have been made where low-solids-content, fine-grained slurries have been pumped into fairly open woven geotextile tubes without liners and the geotextile was unable to retain the slurry. This behavior points out the importance of a careful design of the overall system. If a slurry containing fine-grained soil is pumped into a geotube® with no attempt to match characteristics of the soil with the geotextile components, there is a real possibility that the geotube® will:

a. Clog completely and retain high water content in the encapsulated slurry for an extended or even indefinite period.

b. Fail to retain soil particles, and allow unfiltered slurry to escape through the fabric and re-enter the water column.

Contraction Dikes at Red Eye Crossing, Baton Rouge, LA

Red Eye Crossing is a 2-mile reach between bends in the Mississippi River below Baton Rouge, LA, where the navigation channel crosses from the left (west) bank to the right (east) bank as the river flows downstream. Sediment is deposited in the navigation channel throughout the year, and dredging is required to maintain navigability of the ship channel. Dredging is such an expensive undertaking that alternative measures were explored and evaluated. For example, one alternative examined was underwater contraction dikes constructed at right angles to the riverbank to maintain water velocity in the navigation channel and keep soil particles in suspension.

The most economical method of building contraction dikes at Red Eye Crossing was shown by Duarte, Joseph, and Satterlee (1995) to be stone construction. However, representatives of the navigation industry expressed concern that rigid stone barriers adjacent to the navigation channel would pose the problem of collisions and spills from ships that run aground. As a result, soft dikes made of geotextile shells filled with sand were proposed to address the concerns of the industry. Collisions of ships with soft dikes would be no more severe than collisions with sandbars or earthen banks that exist naturally in the river environment.

Six dikes varying in length from 600 to 1700 ft for a total of about 7000 linear ft were constructed in 30 to 70 ft of water by dropping geobags® and geocontainers® filled with sand. Construction took place between July 1993 and July 1994. Current in the water at the surface ranged from 2 to 5 ft/sec during the construction period. The contraction dikes were constructed to be a minimum of 15 ft high with a crown width of 5 ft, and side slopes of 1V on 2H. The material used to fill the bags and containers was a medium to fine, clean Mississippi River quartz sand that is classified SP according to the Unified Soil Classification System (USAEWES 1960). The sand was obtained from a borrow pit downstream of the construction site; its grain-size distribution is shown in Figure 9.

The geotextile geobags® and geocontainers® used to construct the Red Eye contraction dikes were manufactured from the geotextile, Nicolon HP570. No liner was used in the sand-filled elements. Properties of HP570 as determined and reported by the Nicolon Corporation are given in Table 5. Typical tensile pull-elongation characteristics of Nicolon HP570 are shown in Figure 6.

The large geocontainers® used for the construction were roughly rectangular in shape and constructed to fit the hopper of a modified split-hull, bottom-dump scow that was used to transport and place the geocontainers®. The circumference of each geocontainer® was about 45 ft and the length ranged from 40 to 115 ft. Circular vents made from a 20 AOS geotextile were placed in the ends and tops of the geocontainers® to facilitate the escape of air and decrease the danger of rupture upon striking the bottom. However, this practice was later judged to be unnecessary.

Production filling of geobags® took place on the deck of a flat-deck barge using a hopper-fed conveyor belt system. The result was a pillow-shaped structure about 9 ft high and 12 ft in circumference. Empty geobags® were placed inside a cradle specially designed to hold, support, and handle the geotextile shell after it was filled. Upon filling, the bag was sewn shut with electric powered (120 vac) hand-held sewing machine, and the cradle and geobag® were picked up by a modified front-end loader, transported to a predetermined location on the deck of the barge, and dropped into the river.

Over 38,000 3-cu-yd geobags® along with 556 geocontainers® filled with 200 to 550 cu yd of river sand were used to construct 15-ft-high underwater contraction dikes. Brightly colored and numbered floats were placed in some of the geobags® and geocontainers®. Therefore, if floats are observed and recovered after placement, not only is the occurrence of rupture confirmed, the specific ruptured geobag® or geocontainer® is identified.

Performance of instrumented containers and bags

Three 115-ft-long geocontainers® were instrumented with strain gages and pressure cells before they were dropped in 70 ft of water. The purpose of the strain gages was to determine the state of strain in the geotextile and the activity producing maximum strain. The purpose of the pressure cells that were placed inside and outside the geocontainer® was to determine the velocity of the container as it

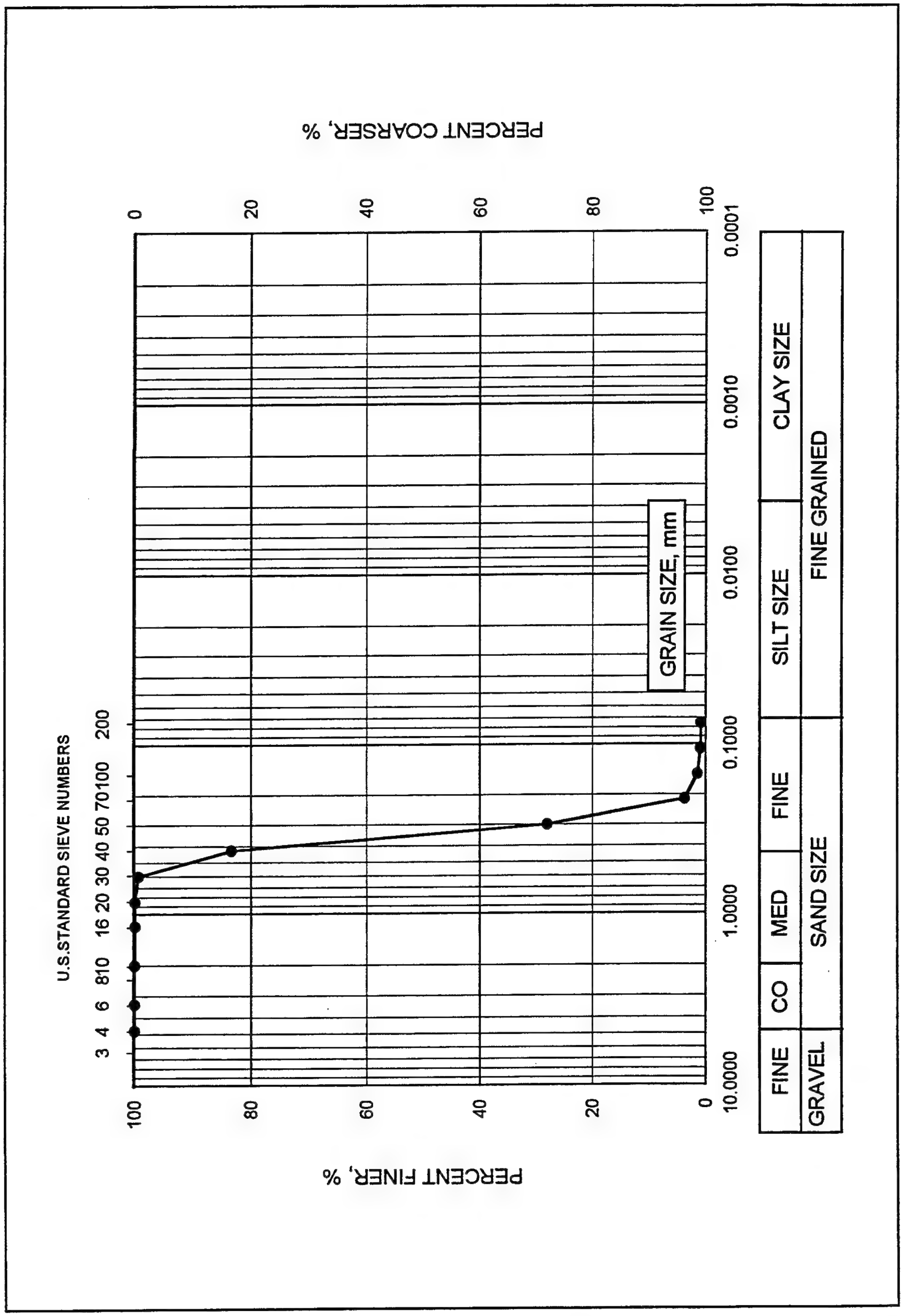


Figure 9. Grain-size distribution of Red Eye Crossing sand

dropped to the riverbed. Velocity was computed from the measured rate of change of pressure as the containers settled through the water column.

Ten strain gages were placed along the 45-ft circumference of the geocontainers® to quantify strain in the containers as they (a) dropped from the bottom-dump scow, (b) settled through the water column, and (c) struck the river bottom (Fowler et al. 1995). Gage readings showed that maximum strain in the geotextile occurred as the geocontainers® slid out of the split-hull scow hopper; strains between 8 and 12 percent were recorded during this action. Geotextile strains occurring as the result of the geocontainers® impacting with the river bottom were between 3 and 4 percent. Terminal velocity was reached within one-half second after the container was free from the hopper. Measured terminal velocities ranged from 12 to 15 ft/sec for both the geobags® and geocontainers®.

Three geobags® were instrumented and dropped into the river, falling 8 to 9 ft through the air before striking the water surface. The strain gage readings showed a maximum strain between 3 and 8 percent that occurred when the bags impacted the water surface.

Monitoring the site showed that, out of 3500 geobags® equipped with floats, 6 ruptured, representing less than 0.2 percent of the total. The geobags® that ruptured did so within 5 days of placement, and the breaks were judged to be associated with a problem with the geobags® sliding off the cradle. After adjustments to the cradle were made, no more ruptures occurred.

Of the 160 geocontainers® equipped with floats that were placed in the dikes during construction, 6 ruptured, representing about 3.8 percent of the total. Duarte, Joseph, and Satterlee (1995) conclude that field seams were the weak link in the operation and were likely responsible for some of the ruptures. They also suggest that, even though fewer ruptures occurred after an adjustment was made to the field seaming technique, seaming remains the most uncertain activity in the construction sequence, and additional improvement and refinement are essential.

Results of operations at Red Eye Crossing

Construction of the contraction dikes took place at high river stage. Current drift was taken into account by periodically measuring the drift of geobags® and geocontainers® during placement. Data presented by Duarte, Joseph, and Satterlee (1995) show that the drift of geobags® took place at a 1V to 1H slope for construction at Red Eye Crossing. Inspection of the dikes during low river stage when some of the dike was exposed showed that the construction effort had, indeed, produced submarine dikes with a 1V on 2H slope as can be seen in Figure 10. Inspection showed, also, that a few of the bags had received minor damage from floating debris, and some had been substantially damaged by propeller strikes from vessels such as towboats, as seen in Figure 11. However, such damage occurs only in shallow water near the shoreline. Neither floating debris nor propellers of

Figure 10. Underwater contraction dike at Red Eye Crossing

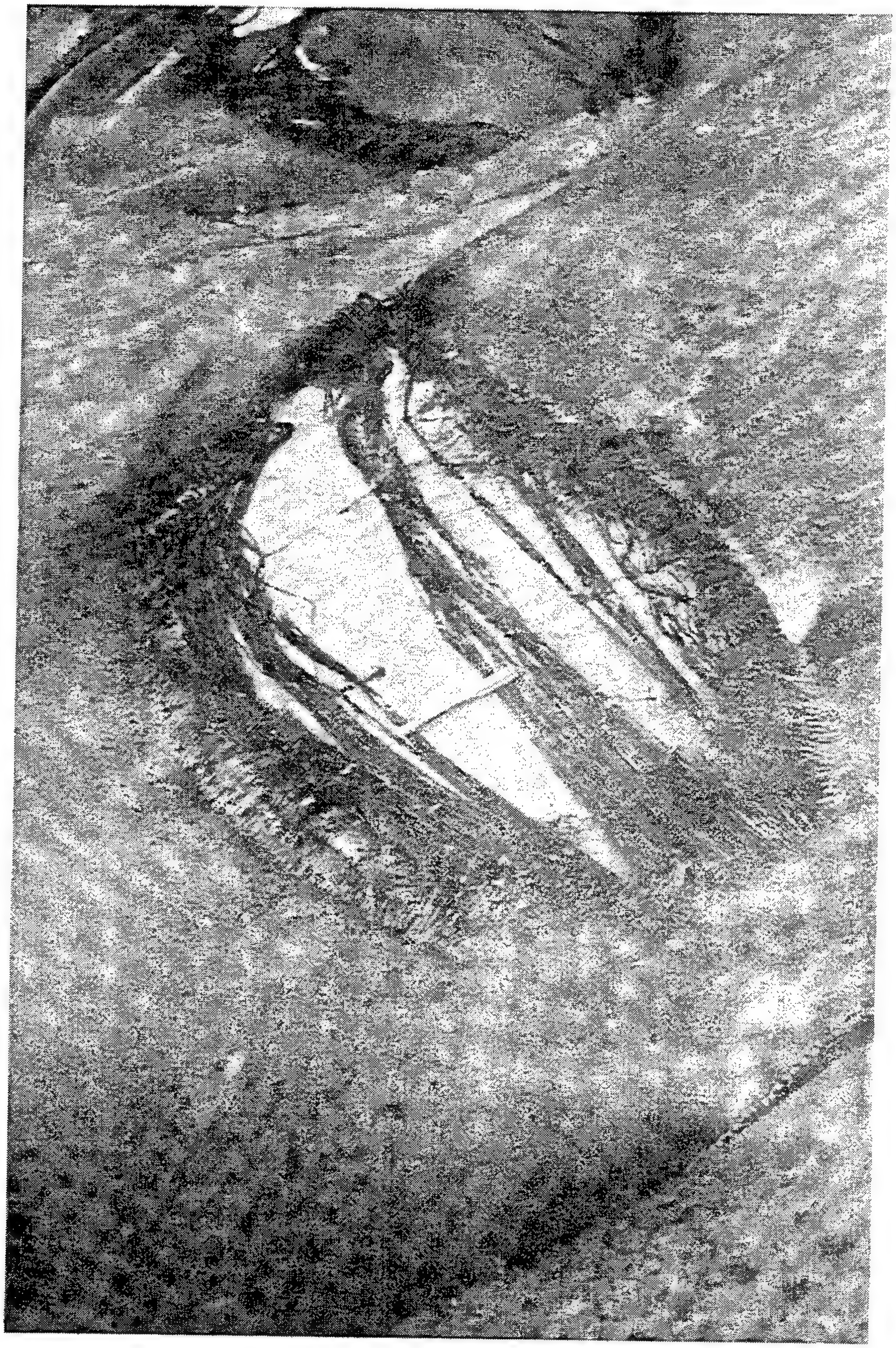


Figure 11. Propeller damage to geotextile element

shallow-draft vessels will reach the bags and containers in deeper water where the contraction dikes continue to perform as expected.[1]

It was observed during inspection of the dikes that sand was lost through the surface of some of the bags and containers. The geobags® and geocontainers® used at Red Eye Crossing consisted of a single layer of Nicolon HP570, which has an AOS equal to the No. 30 U.S. Standard Seive. Nearly 100 percent of the sand used to fill the geobags and geocontainers passed the No. 200 Standard Sieve, suggesting that by the criteria of Task Force No. 25, AASHTO (1990), the geotextile AOS should be greater than the No. 50 U.S. Standard Sieve. Therefore the criteria of Task Force No. 25, AASHTO (1990) were not met, and consequently sand was lost from the containers. A simple and inexpensive solution to prevent such loss of sand through the surface of the geotextile and increase the life of the underwater structures is to provide a nonwoven liner inside the geobags® and geocontainers®.

Since construction of the dikes at Red Eye Crossing in 1994, dredging costs have been reduced by about two-thirds from a maximum of $5 million to less than $2 million per year, virtually paying for the cost of the dikes.[1]

Placement of Contaminated Dredged Material, Marina del Rey, Los Angeles, CA

Marina del Rey Harbor is located on the Pacific Ocean at the mouth of Ballona Creek in Los Angeles, CA. Over time, sediment unsuitable for open-water disposal accumulated in the entrance channel to the harbor. Since the sediment buildup was an impediment to navigation, the U.S. Army Engineer District, Los Angeles, determined that 132,000 cu yd of the bottom sediment should ultimately be removed to deepen the entrance channel. Plans were made to remove the sediment by dredging with a clamshell bucket equipped with a silt screen to minimize and localize turbidity in the water column.

Soil characteristics

Special care and handling of the dredged material were planned because it was contaminated with a number of heavy metals, polychlorinated biphenyls (PCB), polynuclear aromatic hydrocarbons (PAH), phthalates, organnotins, and conventionals such as oil and grease, hydrocarbons, sulfides, and ammonia. The presence of elevated concentrations of lead, copper, and zinc in some of the sediment makes it unsuitable for open-water disposal. A grain-size distribution of typical material taken from the site is shown in Figure 12; the soil is classified in the Unified Soil Classification System (USAEWES 1960) as a poorly graded medium to fine sand

---

[1] Personal communication, 1996, Frank Duarte, Civil Engineer, U.S. Army Engineer District, New Orleans, New Orleans, LA.

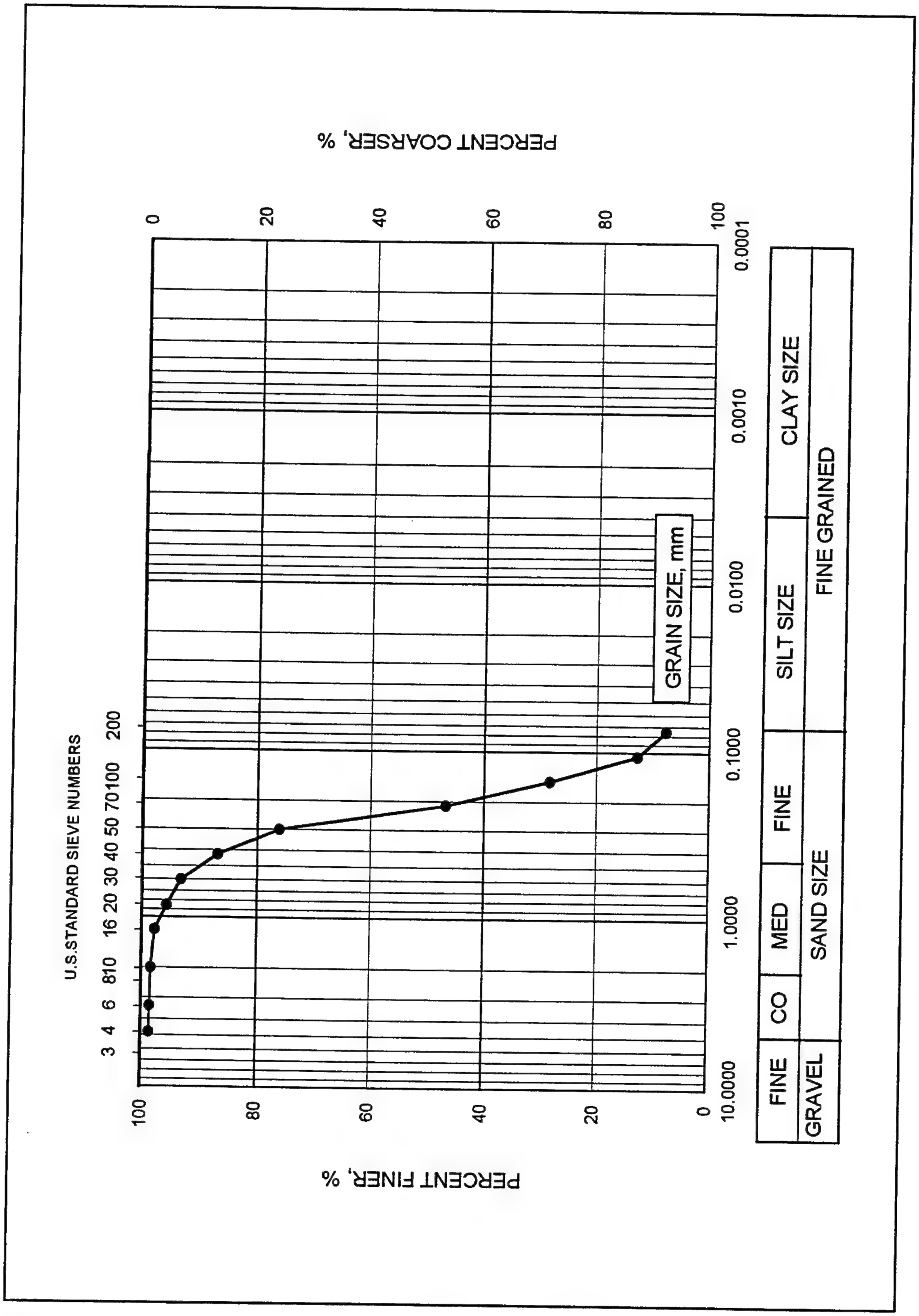


Figure 12. Grain-size distribution of Marina del Rey sand

(SP). It is fairly clean (meaning free of silt and clay), containing only about 8 percent silt and clay-size particles and is uniform in grain size (coefficient of uniformity is 2.7).

Direct shear tests on Marina del Rey sand

Direct shear tests were performed on sand taken from Marina del Rey Harbor to determine the angle of internal friction, ϕ. Three rectangular parallelopiped specimens of sand were tested that were 3 in. square in plan and about 1/2 in. in height. The specimens were tested in a direct shear apparatus in which vertical loads were applied and maintained with pneumatic pressure cylinders. The rate of deformation used was 0.500 in. applied in a period of 15 minutes; the specimen was covered with water during shear.

Specimens were molded by spooning an amount of sand into a direct shear box and rodding the sand with a 1/8-in.-diameter brass rod until the specimens were 1/2 in. in height. Operating in this manner produced specimens with average dry densities of 97.5, 99.4, and 100.4 lb/cu ft that were tested under vertical stresses of 6.9, 13.9, and 41.7 psi, respectively. In molding specimens, sand was taken from a container filled with water and spooned into a mold filled with water; rodding was not energy-intensive or rigorous since the intention was to produce a density characteristic of that in the geocontainers® estimated to be about 97 lb/cu ft.

The horizontal stress-deformation curves for the tests performed are shown in Figure 13. Based on data presented in Figure 13, the strength envelope is shown in Figure 14. The angle of internal friction computed from peak values, ϕ_p, is 34.1 deg; conversely, the angle of internal friction computed from residual values (at a deformation of 0.4 in.), ϕ_r, is 32.4 deg. It must be noted that these friction characteristics were determined at an average density of about 99 lb/cu ft dry density. If dry density in soil within the container is greater than 99 lb/cu ft, then friction angles will be correspondingly higher.

Planned placement method

The procedure planned for placement of contaminated sediment involved depositing dredged material into the hopper of a bottom-dump scow that was lined with a suitably designed geotextile composite system, sewing the geotextile system after filling to form a closed container,[1] dropping the containers in 35 to 40 ft of water in a designated disposal area, then covering the area with a 10- to 15-ft-thick cap of clean (i.e., uncontaminated) soil. The composite geotextile system used was Nicolon GT 1000 (for strength and abrasion resistance) lined with S1200 (for enhanced filtration).

[1] Containers are 90 ft in circumference and 200 ft long.

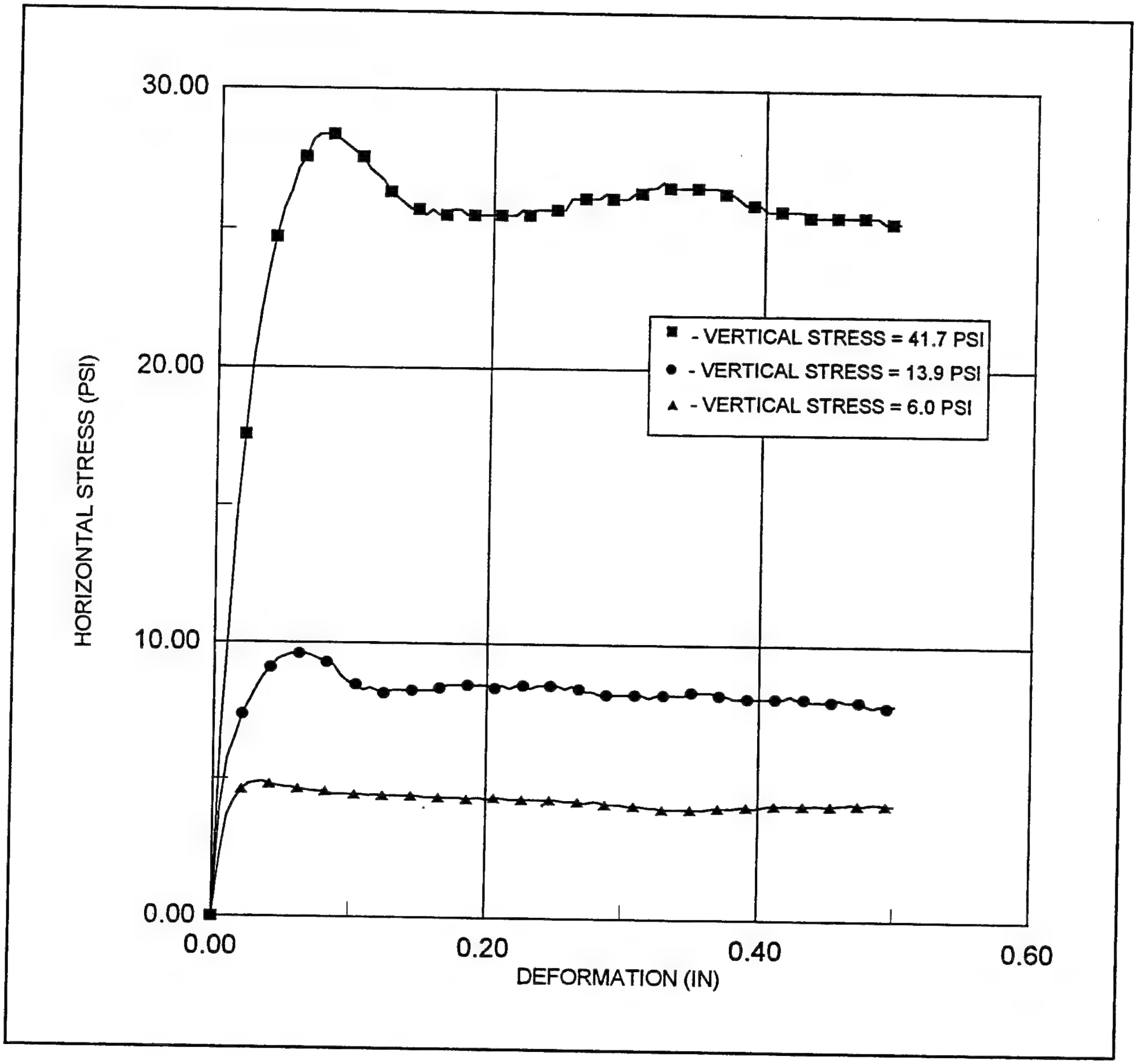


Figure 13. Direct shear tests on Marina del Rey sand

Geocontainer® lodged in scow

The first attempt to fill and place a geocontainer® of dredged material resulted in the shell and encapsulated soil becoming lodged in the hopper of the bottom-dump scow. A schematic of the hopper section used at Marina del Rey is shown in Figure 15. About 1900 cu yd of dredged material were placed in the hopper to fill it within 5 ft of the top. The container and its contents seized as they moved through the opening at the bottom of the scow. The container became so tightly wedged and rigid that it was qualitatively described by divers who inspected it as "hard as a rock." Knowledge of soil behavior suggests that for the geotextile encapsulated soil system to drop from the hopper, the soil must be in a state where it yields

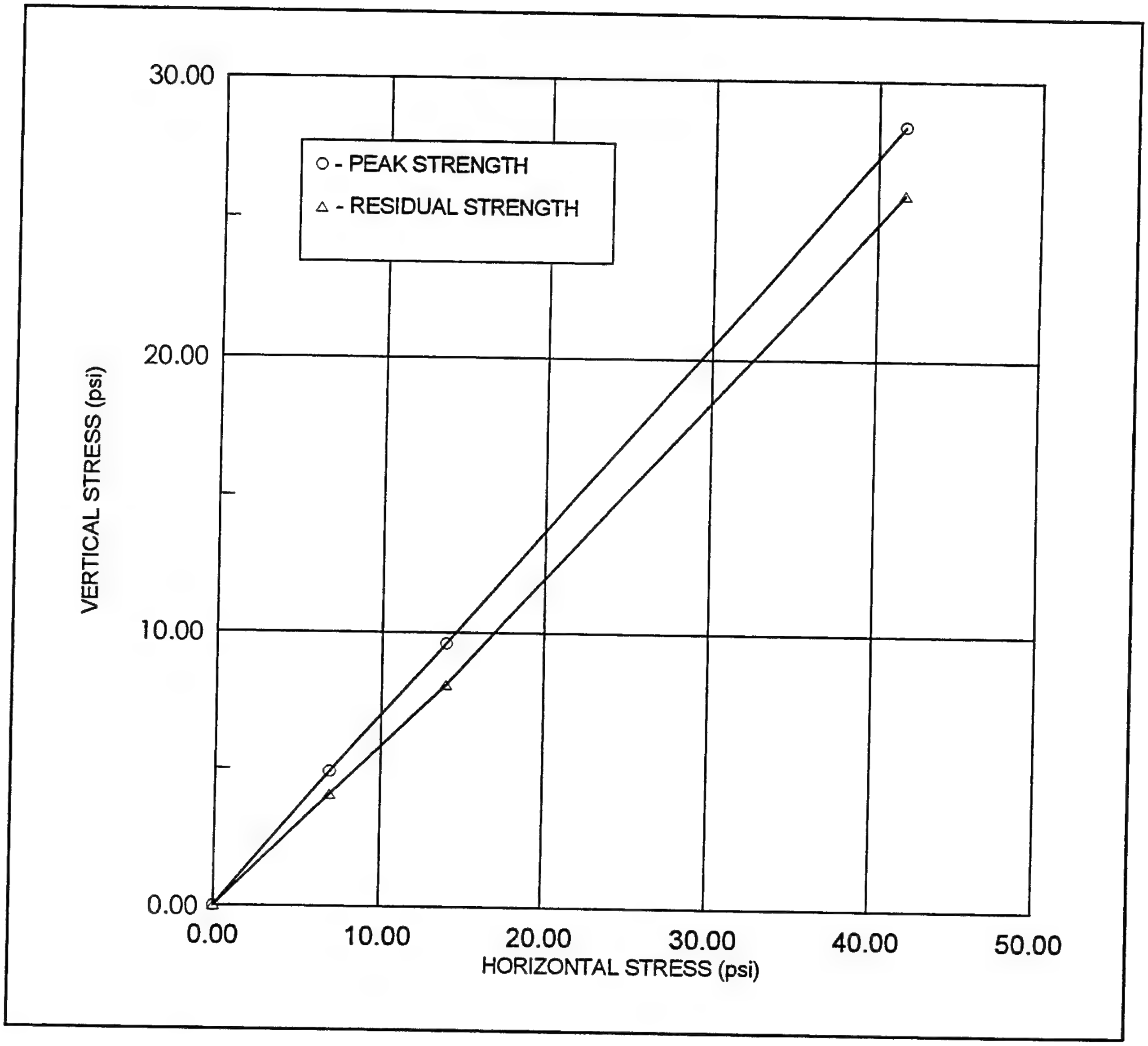


Figure 14. Strength envelope for the Marina del Rey sand

continuously (i.e., flows) inside the geocontainer®. Yielding or flow conditions in soils are promoted by low strength and factors that lower strength. The fact that the density of the soil (and therefore the friction angle) is relatively high suggests high strength and the tendency for stability and rigidity of soil in the container. Additionally, the soil was unsaturated which adds another component of strength, that of apparent cohesion.

As stated above, the container lodged in the hopper and its removal may have been hampered by arching, which is the tendency for granular materials to bridge over openings. Hence, arching was considered to affect behavior of the encapsulated soil system since the soil involved was granular, possessed significant frictional strength, and the plan was to discharge the material through a "trapdoor" that opened at the bottom of a bin.

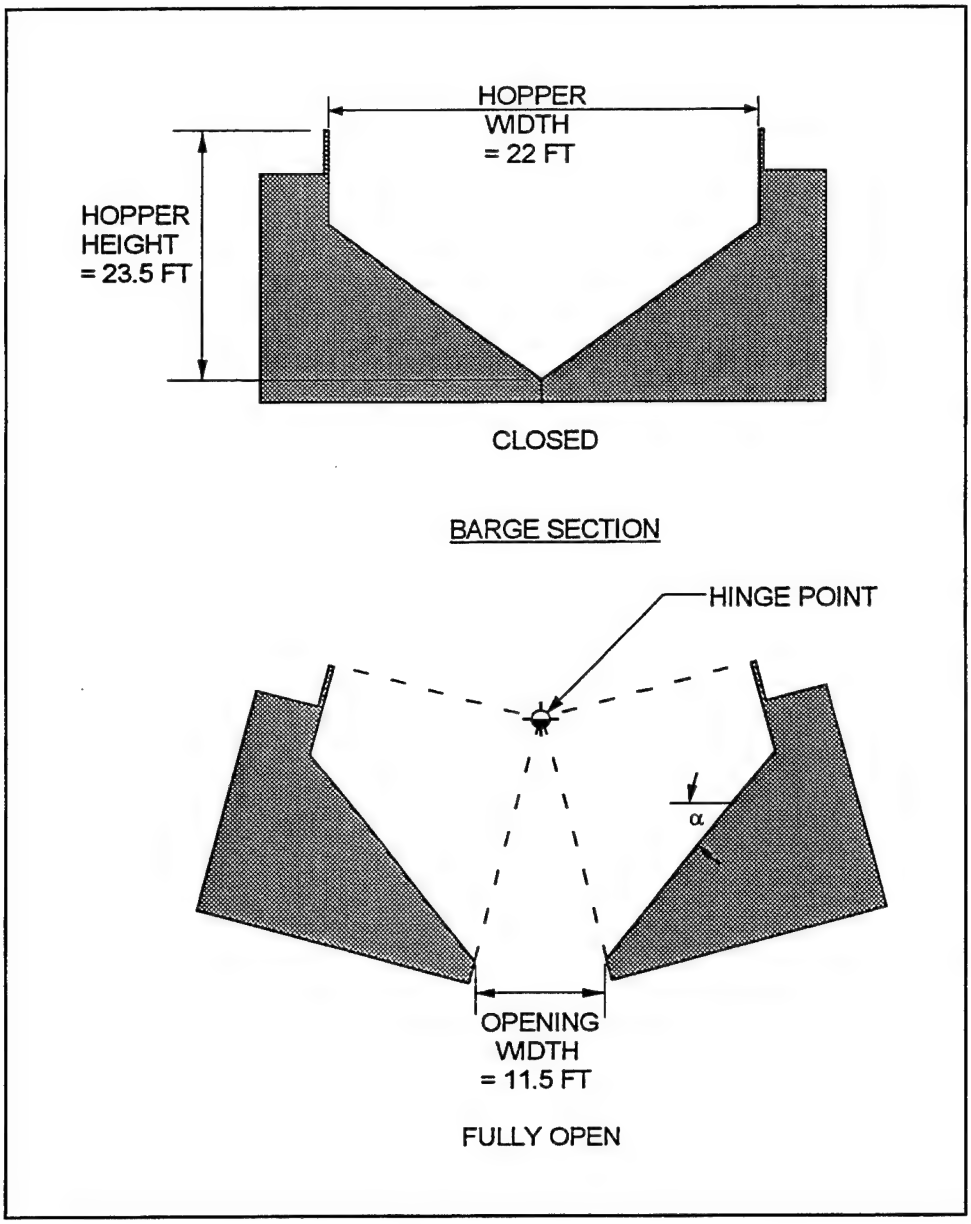


Figure 15. Bottom-dump scow section used at Marina del Rey

Terzaghi and Peck (1948) describe arching in hoppers; their method of analysis along with data furnished by McNulty (1965) are discussed in Appendix B. The analysis in Appendix B shows that if the ratio of height in a hopper to width of door at the bottom is 1.5 or greater, there is a substantial probability that arching will cause bridging across the opening. In the first filling of a scow at Marina del Rey, the ratio of height to opening width was 17.5 ft to 11.5 ft, slightly more than 1.5.

Various techniques were tried in an attempt to dislodge the geocontainer®; the unsuccessful techniques used were:

a. Bumping the scow with a towboat to dislodge the container with vibrations.

b. "Massaging" or "kneading" the container by pressing with the jaws of the scow to soften the (soil) contents.

c. Flooding the hopper with 5 ft of water to surcharge the container and force it through the opening in the scow.

The technique that proved successful in dislodging the container was injecting water at a high flow rate[1] into the center of the soil mass inside the geocontainer® through a diffuser pipe. More than 2 hr of continuous injection was required before the geocontainer® dislodged.

The unsuccessful techniques described above were ineffective in removing the geocontainer® because they did little to change the strength or structure in the soil. Bumping the scow with a towboat to vibrate the soil did little to change the apparent cohesion or density of the soil, as did applying pressure with the jaws of the scow. Filling the hopper with 5 ft of water amounted to applying a surcharge of only about 2 psi, which was inadequate to move the geocontainer®.

However, injecting a large volume of water into the container served to:

a. Break up arches that had formed in the soil mass.

b. Increase the saturation of the soil mass.

c. Decrease the strength of the soil by decreasing the apparent cohesion and grain contact pressure.

During the next filling, the quantity of dredged material deposited in the hopper was reduced to 600 cu yd to result in a height in the hopper of about 8.4 ft and an H/B ratio of about 0.7. This geocontainer® dropped easily from the scow. The circumference of the geocontainer® was then increased from 90 to 120 ft and the amount of dredged material increased incrementally up to about 1300 cu yd where a slight reluctance to pass from the scow was observed. From that point, 1300 cu yd was used as the maximum safe load; 1300 cu yd filled the hopper to within 10 ft of the top, and resulted in an H/B ratio of 1.16. Additionally, an excess of fabric was pleated at the bottom of the hopper to allow soil to fall into the pouch that formed when the hull opened. Operation in this manner facilitated removal of the geocontainer®.

Results of operations at Marina del Rey

Approximately 55,000 cu yd of contaminated maintenance dredged material was successfully encapsulated in 44 geotextile containers and placed with split-hull,

[1] A Los Angeles fire boat pump with a maximum discharge capacity of 2000 gpm was used to inject water into the geocontainer®.

bottom-dump scows in a shallow water habitat and capped with a 12-ft-thick layer of clean sandy dredged material (Risco 1995). The containers were placed within the Port of Los Angeles Shallow Water Habitat Confined Aquatic Disposal site.

Percent total solids tests and chemical tests were conducted on water and dredged material sediment that passed through the nonwoven polyester fabric. The percent concentration of solids remaining after evaporation of the water and sediment that seeped through the nonwoven fabric ranged from about 2.57 to 3.70 percent total solids. Salinity content of the water was not determined; however, it is known that dissolved solids in seawater varies from about 2.5 to 3.0 percent. Therefore the total suspended solids in the seepage water ranged from a minimum of about 0.07 to a maximum of 1.2 percent.

Placement of Contaminated Dredged Material, New York Harbor

Approximately 5-7 million cubic yards of sediment must be dredged from New York Harbor each year to keep the port operational (Clausner and Welp 1996). The Mud Dump site is a dredge material disposal site about 1 mile long by 2 miles wide located in the Atlantic Ocean about 6 miles off the coast of New Jersey and about 15 miles southeast of the Verrazano Narrows Bridge. Water depth at Mud Dump site varies from less than 50 ft over a small area to between 70 and 85 ft over a much larger area, with a substantial part of the site being more than 100 ft deep (Oceaneering International, Inc. 1996). The Mud Dump site is the only existing open-water disposal facility available to material from the New York Harbor; however, Mud Dump has limited capacity, particularly for receiving contaminated sediment. Recent changes in the regulations that control open-water disposal have reclassified contaminated sediment to the point that over half of the material removed from New York Harbor is now considered contaminated. Therefore an economically and environmentally viable alternative to dredged material placement in the Mud Dump site is essential.

In April 1995, the Port Authority of New York and New Jersey conducted a demonstration of dredged material disposal by encapsulation and placement of 3700 cu yd of dredged material in a single geocontainer® using a bottom-dump split-hull scow (Fowler 1995). In June 1996, the Port Authority of New York and New Jersey and the U.S. Army Engineer District, New York, jointly demonstrated placement of two geocontainers® filled with about 1600 cu yd each (Clausner and Welp 1996). The scows used at New York Harbor were similar to those at Red Eye Crossing and Marina del Rey in operation and function. The cross section with dimensions of scows used in the June 1996 demonstration are shown in Figure 16; hoppers in the scows were 176 ft long.

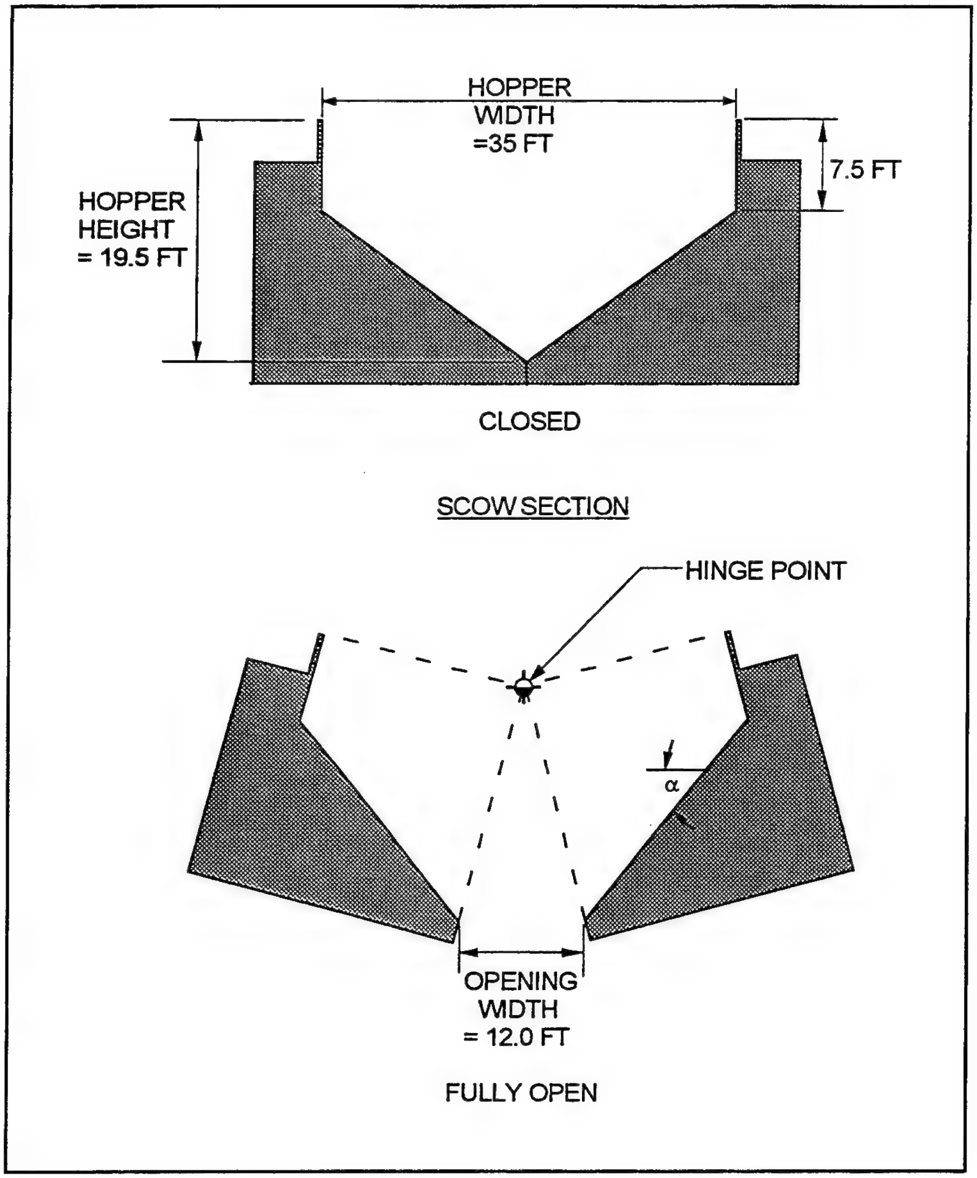


Figure 16. Bottom-dump scow section used at New York Harbor

Soil characteristics

Sediment removed from New York Harbor during the June 1996 demonstration was a fine-grained dark gray silt with a liquid limit of about 130 (percent water content) and a plasticity index of about 56 (percentage points). The specific gravity of the material ranged from 2.64 to 2.69; its grain-size distribution is shown in Figure 17. The soil was mechanically dredged from its in situ location, temporarily stored in the hopper of a split-hull scow, then pumped along with additional water into a geocontainer® that had been placed in the hopper of a second split-hull scow. The geocontainers® used were 195 ft long, 105 and 120 ft in circumference, and were filled through an inlet port located at top and center of each geocontainer as it lay in the hopper. The dredged material deposited in the geocontainers® for

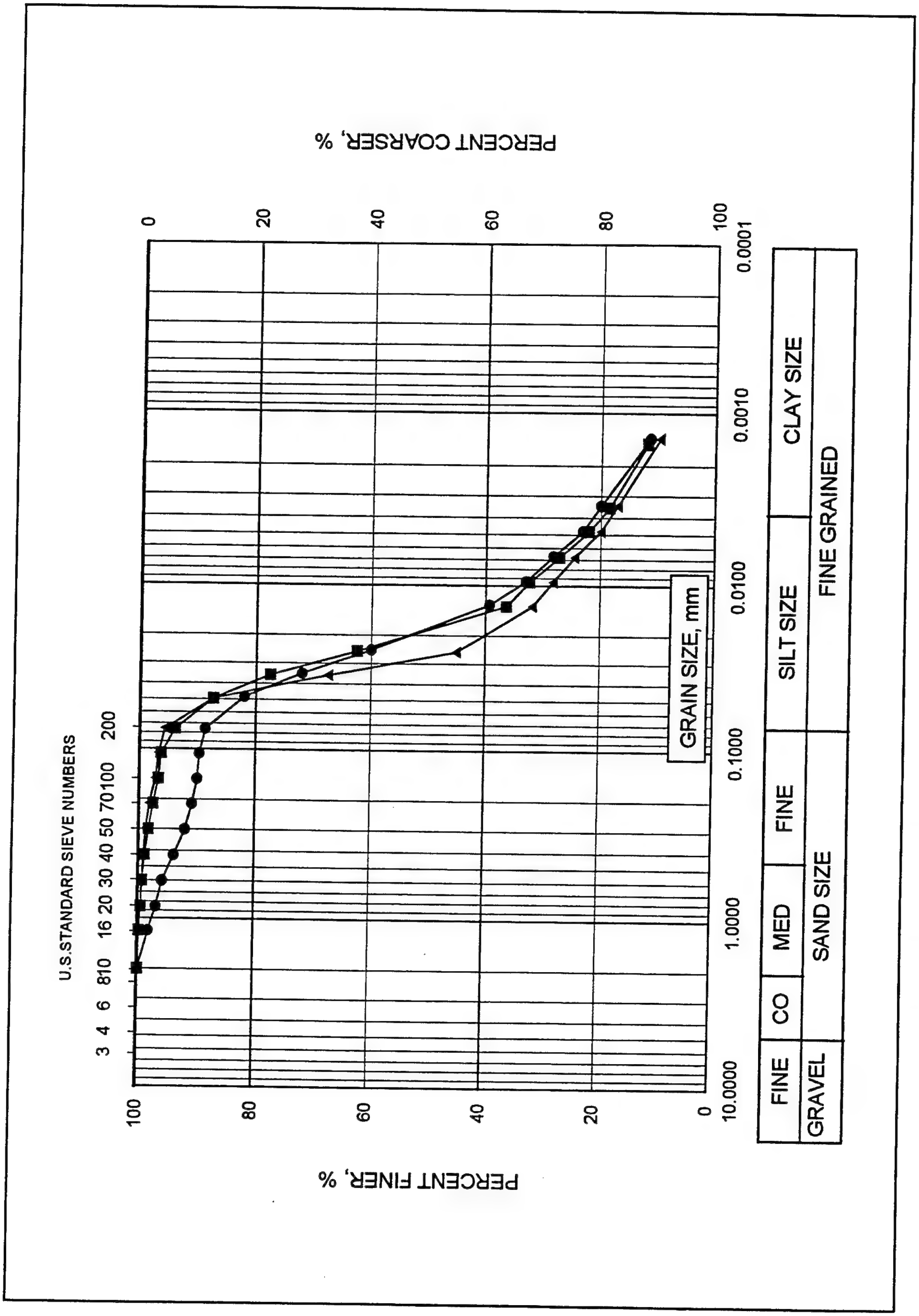


Figure 17. Grain-size distribution of New York Harbor soil

placement during the June 1996 demonstration had a bulk density of about 1.18 g/cm^3 for a solids content of about 22 percent and a water content of about 350 percent (which is 2.7 times as great as the liquid limit).

Performance of geocontainers® at New York Harbor

As stated above, the dredged material removed from New York Harbor was predominantly a fine-grained soil, having typically less than 10 percent sand-sized particles. Additionally, the material was placed in the geocontainer® at a water content that is about 2.7 times the liquid limit. As such, the soil behaved as a nearly frictionless fluid. Palmerton (1996) used the distinct element method (DEM) to analyze the hopper/soil/geocontainer® system. The DEM finds the solution for a system of distinct rigid bodies acted on by applied and gravity forces using Newton's second law of motion (i.e., F = Ma). Palmerton (1996) models soil motion inside a geocontainer® and simultaneously models geocontainer® motion in the hopper of a scow that opens progressively using a large number of small disk-shaped elements. Two-dimensional, plane strain conditions are assumed in the analysis and considered reasonable since the length of the scow is large relative to the planar dimensions shown in Figure 16. Scow boundaries opening are represented using several bar-shaped elements; the geocontainer® is simulated by disk-shaped elements that are joined together by a flexible yet inextensible linkage. The angle of internal friction between soil particles used in the analysis by Palmerton (1996) in analysis of the June 1966 New York drops is 1 deg, which simulates behavior of a nearly frictionless fluid.

Three modes of failure are possible in discharging a geocontainer® from a bottom-dump scow:

1. The geocontainer® seizes/wedges in the hopper and will not discharge.

2. The geocontainer® ruptures due to excessive tensile strain in the fabric as the package is discharged through the opening in the hopper.

3. The geocontainer® ruptures due to excessive tensile strain in the fabric as the package strikes the ocean bottom.

Failure mode 1, for example, occurred at Marina del Rey. This mode usually occurs as the result of friction between grains of a granular soil that results in mass stability; the wedging that resulted may have been aggravated by arching. Failure mode 2 is considered to have occurred during the April 1995 drop based on observation and analysis by Palmerton (1996). Similarly, failure mode 3 is concluded to have occurred during the second June 1996 drop based on observation, analysis of data acquired from instrumentation of the geocontainer®, and DEM analysis.

Additionally, Palmerton (1996) concluded that the first geocontainer drop of June 1996 failed because the container was torn before the scow doors were opened at the Mud Dump site. An extra 15 ft of fabric was pleated at the bottom of the hopper as it was during the Marina del Rey operations. Palmerton (1996) states,

"The presence of the extra 15-ft-wide lapped panel at the bottom of the scow permitted the fabric to descend between the closing bars of the scow and unknown agents weakened or tore the fabric." It is, in fact, suspected that jagged metal protrusions about and underneath the closing bars of the scow may have damaged the geotextile shell during transit to the placement site.

An additional response that may warrant consideration is that the two halves of a bottom-dump scow are like beams and are loaded by the dredged material inside the hopper. If the dredged material applies uniform loading along the length of the simply supported beams forming the two halves of the scow (and the loading may be substantial), then considerable deflection may result in the center of a span that may approach 200 ft. The deflection that occurs may, in fact, allow the encapsulating geotextile system to descend between the deflected bars/beams and be damaged during transit in a manner similar to that described by Palmerton (1996). To alleviate this potential problem, a structure to bridge the gap created by the deflection may have to be placed in the bottom of the hopper.

Although the DEM has been used to great advantage for analysis of a hopper/soil/geocontainer® system within a scow, it is acknowledged that the method as used by Palmerton (1996) is two-dimensional. Whereas two-dimensional plane strain representation of this problem is arguably sound, it does not address the reality and complexity of the three-dimensional situation that exists in a scow operating in the field.

Economics of Geotextile Encapsulation

A careful economic analysis is necessary in each situation where the use of geotextile encapsulation is envisioned, regardless of the geosynthetic product manufacturer. It must be stated, however, that quality in a manufactured geotextile is crucial because of the high cost of field construction and because product failure in the field can cause severe and irreversible environmental damage. From this perspective, use of geosynthetic products from established vendors with good reputations, capability for technical support, and proven "track records" is highly recommended.

The economic analysis must not only consider direct costs of required materials, but also ease of construction and environmental impact. Economic analysis is important for comparison of alternatives, since high costs associated with the use of geotextile tubes and containers restrict their use to projects where storage capacity for dredged material is limited, or where conventional options are unavailable, environmentally unacceptable, or prohibitively expensive. Fowler (1995) writes, "The cost of fabrication, placing and sewing closed the container with fine grained dredged material in a geotextile container and placing it with a 4,000 yd^3 split hull dump scow was about \$10/yd^2/yd^3 or \$35,500 per container. These costs do not include dredging and other costs."

Costs of placing dredged material in water of moderate depth may, in fact, be considerably in excess of the \$35,500 for each load as quoted by Fowler (1995)

because, in addition to container fabrication and installation costs, there are costs associated with modifying a barge/scow to receive containers, and costs associated with preparation for dredging. Additionally, the rental, lease, or purchase of scow(s) and any other specialized equipment (such as cranes and hydraulic dredges) must be considered as part of the total cost. In this sense, a construction sequence should be planned and designed to utilize equipment to the fullest extent possible; equipment sitting idle for extended periods is a waste of resources.

Economic analysis of an operation to remove and encapsulate dredged material and place it in a submarine site involves more than the cost of the geotextile shell. All activities involved in the process are time and labor intensive; as such, they involve costs that must be taken into account for a correct and complete economic evaluation of the use of geotextile encapsulation for construction or for placement of dredged material.

8 Conclusions and Recommendations

Conclusions

Based on experience gained during this investigation the following conclusions and recommendations are warranted:

a. Geobags®, geotubes®, and geocontainers® as described above refer to designed systems of geotextiles to encapsulate soil for use as structural elements, or encapsulation for the purpose of removing and isolating soil from the environment. The encapsulated units have been used to achieve economic and practical solutions to geotechnical engineering problems not possible using conventional technology. Construction of underwater contraction dikes for sedimentation control is an example of innovative construction achieved with geobags® and geocontainers® that proved economically and technologically successful.

b. Sound methodology for the design of long cylindrical tubes (geotubes®) that are partially to totally submerged in water was developed and presented as an interactive computer code. Required strength for the geotextile shell as well as the filled tube geometry is determined during a design procedure where appropriate safety factors are applied to various engineering aspects of the filled tubes. The design code, called GeoCoPS, was prepared for single tubes resting on flat, rigid bases.

c. Geotextile tubes develop essentially no pressure at the top surface of the filling fluid until they are about one third of their design height and about two thirds of their design cross-sectional area. However, once internal pressure develops from a constant rate of filling, it increases quickly and can result in tube rupture. GeoCoPS can be used to determine the design pressure required for a given cross section; exceeding the design pressure results in small increases in tube height and storage, but substantially increases the risk of rupture.

d. Removal and placement of dredged material by encapsulation in a geocontainer®, transportation by hydrobarge or split-hull bottom-dump scow to an

offshore site, and dropping the package in deep water is, in principle, a viable means to deal with contaminated or otherwise undesirable soils. However, problems have been encountered with split-hull bottom-dump scow placement of geocontainers®. Some containers have ruptured during attempted release from the scow, others have become wedged in the hopper, and still others have been damaged during transport and, as a result, have failed during release. Analysis of the complex geotextile/soil/hopper system comprising the problem has been achieved using the distinct element method (DEM). However, the DEM is basically a research tool that cannot be used for routine design.

e. Experience suggests that problems with geotextile/soil/hopper systems are associated with overfilling the hopper, damage to geotextiles during installation and transit inside the hopper, as well as the width to which the hopper opens during discharge of the container. Analysis of measurements made by instrumenting geocontainers® suggests that maximum distress may occur from different mechanisms for different soil types. At Red Eye Crossing, maximum distress in the geocontainer® filled with frictional sand occurred as it was discharged from the hopper of a bottom-dump scow. At New York Harbor, maximum distress in the geocontainer® filled with high-water-content plastic clay occurred as the container struck the ocean bottom.

f. Low seam strength is a problem in the geotextile industry that significantly impacts the economics of encapsulated containers constructed from geotextiles. One of the great advantages of geotextiles is that they are easily sewn together to form composite systems to perform specific functions. However, seam strength, as discussed earlier, is about one half that of the woven fabric. Therefore to achieve a given strength in a geotextile shell, the use of a geotextile with twice the required strength is necessary because of the reduced strength inherent in a seam. Therefore, the economy of geocontainer®, geobag®, and geotube® construction may be increased substantially by increasing the strength/efficiency of seams.

g. To minimize soil loss, geotextile systems design should be based on the AOS method developed by Task Force No. 25 of the American Association of State Highway and Transportation Officials (AASHTO 1990). Although the method provides for maximum retention of soil solids by geotextile systems, it is unrealistic to expect no loss of fine-grained soil solids through geotextile filter systems. A certain amount of solids will be lost through the plane of a geotextile, but following the method of AASHTO Task Force No. 25 (1990) ensures minimal loss.

Recommendations

The following recommendations are made:

a. GeoCoPs does not support analysis or design of stacked tubes, i.e., tubes placed on top of other tubes. There are situations and circumstances where

substantial advantage may be gained by stacking tubes, so it is recommended that GeoCoPS be extended to provide analysis and design of stacked tubes.

b. Controlling internal pressure in a geotextile tube is crucially important to prevent rupture during construction; therefore, the use of a standpipe to prevent overpressurization is recommended.

c. The use of geotextile encapsulation for dredged material placement offers an attractive and viable procedure to eliminate undesirable dredged material and is recommended. However, additional research (with the DEM) and field verification demonstrations are needed and recommended to complete development of sound practical design methodology, guidelines, and procedures for safe and reliable hydrobarge placement of encapsulated soil packages. Early difficulty encountered with the procedure should not provoke premature abandonment of this technology.

d. Until sound methodology and practical procedures are developed for hydrobarge placement, on-site research is recommended to determine the limits of performance of the geotextile/soil/hopper system in use. The hopper and barge should be prepared to eliminate metal protrusions that will damage a geotextile container and cause premature failure. The hopper should ideally be treated with a friction-reducing compound or fitted with a liner to reduce/minimize friction between the geotextile and hopper surface. Finally, to determine the optimum hopper loading that will not result in either seizure in the scow, or rupture of the geotextile as it exits, a series of load trials should be performed. Beginning with a small load that drops from the scow without difficulty, the load should be incrementally increased to the point where the load begins to show a slight hesitation to drop. From there, the load should be sensibly reduced to ensure problem-free operation with reasonable load efficiency.

e. Research to develop a seaming technique that achieves greater strength and efficiency is needed and recommended.

f. Even though geotextiles may be used to considerable advantage in geotechnical and coastal engineering, they have the characteristic of being unforgiving if designed improperly, installed improperly, or damaged during installation. Therefore thoughtful planning and design as well as careful monitoring during installation are required. The excellent economy, environmental viability, and technical advantages that are possible using geosynthetics should be pursued through continuous and rigorous programs of construction quality control and construction quality assurance.

9 Commercialization and Technology Transfer

Availability of Nicolon Geotextiles

Nicolon geotextiles and related products used in the case studies and demonstrations described in this report are manufactured by the Nicolon Corporation in Norcross, GA. Sale of Nicolon products is promoted by agreement with more than 40 representative firms throughout the United States. Sales and technical services offices are:

Nicolon Corporation, Inc.
3500 Parkway Lane, Suite 500
Norcross GA 30092
Telephone (770) 447-6272

The Nicolon Corporation offers design, construction, and technical support for specialized and custom applications of geocontainers®, geobags®, and geotubes® through the Geocontainment Division. Additionally, a video produced during this investigation showing construction technique entitled, "Geocontainer," is available from the Nicolon Corporation. Printed information and brochures describing their geosynthetic products, reporting test results, and giving product specifications are also available from the Nicolon Corporation.

Presentation of Information from This Study

Results of various activities within this investigation have been presented at professional meetings and in many informal exchanges. The WES team published papers in national and international conferences and symposia (Fowler and Sprague 1993, Fowler, Sprague, and Toups 1995, and Fowler et al. 1995). Additionally, the design methodology, GeoCoPS, produced as an interactive computer code during the investigation, was described in a WES report (Leshchinsky and Leshchinsky 1996), and in the Journal of Geotechnical and Geoenvironmental Engineering of the American Society of Civil Engineers (Leshchinsky et al. 1996). The WES report, "Geosynthetic Confined Pressurized Slurry (GeoCoPS): Supplemental Notes for

Version 1.0," (Leshchinsky and Leshchinsky 1996) contains a copy of the design code on a 3.5-in. floppy disk; both the report and software are available free of charge from WES. Additionally, a video showing essential operations of the construction work at Red Eye Crossing, entitled "Construction and Deployment of Geobags at Red Eye Crossing on the Mississippi River (#94027)," is available from WES.

Beginning in 1994, results of the investigation have been shared with various agencies of the U.S. Army Corps of Engineers as well as with other federal government laboratories. On 14-18 August 1995, a workshop was conducted in Galveston, TX, in which findings from this investigation were shared with personnel from Corps of Engineers Districts and Divisions within the Federal Government as well as with dredging contractors and users of geotextiles from the private sector. Products and research have been described by the WES team in technical notes and data sheets distributed through the Dredged Material Research Program (DMRP), (Fowler, Sprague, and Toups 1995), and in trade journals, such as the IGS News (Leshchinsky 1996).

References

American Association of State Highway and Transportation Officials (AASHTO). (1990). "Guide specifications and test procedures for geotextiles," Task Force Rep. 25, AASHTO-AGC-ARTBA, Washington, DC, 1-52.

American Society for Testing and Materials. (1995). "Standard test method for measuring thickness of textile materials," D 1777-64 (Reapproved 1975), Vol 7.01, Philadelphia, PA.

__________. (1995). "Standard test method for mass per unit area (weight) of woven fabric," Standard D 3776-85 (Reapproved 1990), Vol 7.02, Philadelphia, PA.

__________. (1995). "Standard test method for hydraulic bursting strength of knitted goods and nonwoven fabrics--diaphragm bursting strength tester method," Standard D 3786-87, Vol 7.02, Philadelphia, PA.

__________. (1996). "Test method for deterioration of geotextiles from exposure to ultraviolet light and water (xenon-arc type apparatus)," Standard D 4355-92, Vol 04.09, Philadelphia, PA.

__________. (1995). "Standard test method for water permeability of geotextiles by permittivity," Standard D 4491-92, Vol 07.02, Philadelphia, PA.

__________. (1995). "Standard test method for liquid limit, plastic limit, and plasticity index of soils," Standard D 4318-93, Vol 4.08, Philadelphia, PA.

__________. (1996). "Standard test method for trapezoidal tearing strength of geotextiles," Standard D 4533-91, Vol 04.09, Philadelphia, PA.

__________. (1996). "Standard test method for tensile property of geotextiles by the wide-width strip method," Standard D 4595-86, Vol 04.09, Philadelphia, PA.

__________. (1996). "Standard test method for breaking load and elongation of geotextiles (grab bag)," Standard D 4632-91, Vol 04.09, Philadelphia, PA.

American Society for Testing Materials. (1996). "Standard test method for determination of apparent opening size of a geotextile," Standard D 4751-93, Vol 04.09, Philadelphia, PA.

__________. (1996). "Standard test method for index puncture resistance of geotextiles, geomembranes, and related products," Standard D 4833-88, Vol 04.09, Philadelphia, PA.

__________. (1995). "Standard test method for measuring the soil-geotextile system clogging potential by the gradient ratio," Standard D 5101-90, Vol 04.09, Philadelphia, PA.

__________. (1996). "Standard test method for measuring nominal thickness of geotextiles and geomembranes," Standard D 5199-91, Vol 04.09, Philadelphia, PA.

__________. (1996). "Standard test method for measuring mass per unit area of geotextiles," Standard D 5261-92, Vol 04.09, Philadelphia, PA.

__________. (1995). "Standard test method for evaluating the unconfined tensile creep behavior of geosynthetics," Standard D 5262-95, Vol 04.09, Philadelphia, PA.

Bogossian, F., Smith, R. T., Vertimatti, J. C., and Yazbek, O. (1982). "Continuous retaining dikes by means of geotextiles." *Proceedings of the 2nd International Conference on Geotextiles, Las Vegas, NV.*

Casagrande, A. (1948). "Classification and identification of soils." *Transactions ASCE*, 113, New York, 901-92.

Clausner, J. E., and Welp, T. L. (1996). "New York Harbor dredged material management plan: Conceptual design geosynthetic fabric container use with confined aquatic disposal pits and level bottom capping," unpublished report prepared for the U.S. Army Engineer District, New York by the U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Delft Hydraulics Laboratory. (1973). "Breakwater of concrete filled hoses," Report M 1085, Delft, The Netherlands.

Duarte, F., Joseph, J., and Satterlee, G. (1995). "Soft dike demonstration project on the Mississippi River." *ASCE Ports '95, 13-15 March,* Tampa, FL, 921-31.

Fowler, J. (1995). "Appendix A—The Port Authority of New York and New Jersey geotextile container demonstration project," TAMS Consultants, New York.

Fowler, J., Bagby, R. M., and Trainer, E. (1996). "Dewatering of sewage sludge with geotextile tubes," submitted for publication in the Canadian Geotechnical Journal.

Fowler, J., and Sprague, C. J. (1993). "Dredged material filled geotextile containers." *ASCE Coastal Zone '93, New Orleans, LA*, 2415-28.

Fowler, J., Sprague, C. J., and Toups, D. (1995). "Dredge material filled geotextile containers." Environmental Effects of Dredging Technical Note EEDP-05-01, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Fowler, J., Toups, D., Duarte, F., and Gilbert, P. (1995). "Geotextile contained dredged material, Red Eye Crossing, Baton Rouge, LA." *Proceedings of WODCON XIV, CEDA*. Amsterdam, The Netherlands.

Illinois Environmental Protection Agency. (1993). "Title 35: Environmental protection, Subtitle C: Water pollution, Chapter I: Pollution Control Board," State of Illinois Rules and Regulations, Springfield, IL.

Koerner, R. M. (1994). *Designing with geosynthetics*. Prentice-Hall, Englewood Cliffs, NJ.

Leshchinsky, D. (1992). "Issues in geosynthetic-reinforced soil." *Proceedings of the International Symposium on Earth Reinforcement Practice, Kyushu, Japan*. Published by Balkema, Rotterdam, 871-97.

__________. (1996). "Geotextile tubes," *IGS News* 12(3), Easley, SC.

Leshchinsky, D., and Leshchinsky, O. (1996). "Geosynthetic confined pressurized slurry (GeoCoPS): Supplemental notes for Version 1.0," CPAR GL-96-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Leshchinsky, D., Leshchinsky, O., Ling, H. I., and Gilbert, P. A. (1996). "Geosynthetic tubes for confining pressurized slurry: Some design aspects," *Journal of the Geotechnical Engineering Division, American Society of Civil Engineers* 122(8).

McNulty, J. W. (1965). "An experimental study of arching in sand," Technical Report I-674, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Oceaneering International, Inc. (1996). "Geosynthetic fabric container demonstration project June 1996 operations plan," prepared for the Port Authority of New York and New Jersey, U.S. Army Engineer District, New York.

Palmerton, J. B. (1996). "Comparison of numerical model to observed and measured behavior geosynthetic fabric container drops, New York Harbor, June 1996," prepared for the U.S. Army Engineer District, New York, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Perrier, H. (1986). "Use of soil-filled synthetic pillows for erosion protection." *Proceedings 3rd Int. Conf. on Geotextiles, Vienna*, 1115-9.

Pilarczyk, K. W. (1995). "Novel systems in coastal engineering: Geotextile systems and other methods -- an overview," Road and Hydraulic Engineering Division, Rijiswaterstaat (Public Works Department), Delft, The Netherlands.

Risco, A. (1995). "FY95 Marina del Rey maintenance dredging project summary," Memorandum for Record, U.S. Army Engineer District, Los Angeles (CESPL-CO-ON).

Silvester, R. (1986). "Use of grout-filled sausages in coastal structures," *Journal of Waterway, Port, Coastal and Ocean Engineering,* ASCE, 112(1), 95-114.

Sprague, C. J., and Fowler, J. (1994). "Dredged material-filled geotextile containers: Case histories, research and upcoming workshops," *Geotech. Fabrics Rep.*, St. Paul, MN, 12(8), 42-54.

Terzaghi, K. (1943). *Theoretical soil mechanics.* John Wiley and Sons, Inc., New York.

Terzaghi, K., and Peck, R. B. (1948). *Soil mechanics in engineering practice.* John Wiley and Sons, Inc., New York.

U.S. Army Engineer Waterways Experiment Station. (1960). "The unified soil classification system," Technical Memorandum 3-357, Vicksburg, MS.

Appendix A
ASTM Standard Test Methods Used in the Geotextile Industry

Principal features and characteristics of geotextiles that need to be defined in formal specifications are usually given in terms of measurements made in accordance with ASTM standard test methods. The test methods that are usually used to specify geotextiles are summarized next.

ASTM D 5261-92, Standard Test Method for Measuring Mass per Unit Area of Geotextiles

Mass per unit area of a geotextile is determined by weighing and measuring geotextile test specimens that are cut from various locations over the full width of a laboratory sample. The tests are conducted in an environment where the air temperature is maintained at 21 ± 2 °C (70 ± 4 °F) with a relative humidity of 65 ± 5 percent. A minimum of five representative samples with a minimum total area of 100,000 mm^2 (155 $in.^2$) are cut from a roll of geotextile. The specimens are each weighed to the nearest 0.1 g, and mass per unit area is determined by dividing the individual masses by the respective areas, then averaging individual values to determine the mean.

ASTM D 3776-85, Standard Test Method for Mass Per Unit Area (Weight) of Woven Fabric

This test procedure is similar to ASTM D 5261-92, except that larger specimens of geotextile are considered. The approved options provided by the procedure are to use:

a. A full piece, roll, bolt, or cut.

b. A full width sample (from a full piece, roll, bolt, or cut).

c. A small swatch of fabric, at least 130 cm^2 (20 $in.^2$).

d. Narrow fabrics that are usually 300 mm (12 in.) or less wide. The recommended sample length is 1 m.

The weights of the samples are determined to within ±0.1 percent of their true weight, and the areas are determined by measuring dimensions to the nearest millimeter. Results are reported as ounces per square yard or square yards per pound. Alternatively, if SI units are preferred, units are reported as grams per square meter or square meters per kilogram.

ASTM D 5199-91, Standard Test Method for Measuring Nominal Thickness of Geotextiles and Geomembranes

Thickness is defined as the distance between the upper and lower surfaces of the planar geotextile as measured under a specific pressure that is applied for a specific time period. The measurement is made under a pressure of 2 kPa (0.29 psi) that is applied for a time period of 5 sec. Dead-weight loading systems are frequently used to apply the required pressure. Thickness may be reported in inches or millimeters.

ASTM D 1777-64 (Reapproved 1975), Standard Test Method for Measuring Thickness of Textile Materials

This is an early standard that was used in the general textile industry before specialized procedures for geotextiles were developed. Pressures specified are 0.005 to 0.5 psi for "soft" materials such as blankets, knit fabrics, and woolens, 0.02 to 2.0 psi for "moderate" fabrics such as worsteds and carpets, and 0.1 to 10 psi for "firm" fabrics such as ducks and felts. This standard is sometimes seen in older specifications, but it has largely been replaced by ASTM D 5199-91.

ASTM D 4632-91, Standard Test Method for Breaking Load and Elongation of Geotextiles (Grab Bag)

This procedure is an index test that provides a method for determining the breaking load (grab strength) and elongation (grab elongation) of geotextiles. In the procedure, a monotonically increasing load is applied to a test specimen and the loading is continued to rupture. Values for the breaking load and elongation of the test specimen are obtained from digital force and displacement measuring instruments, continuous line recording devices, or computers interfaced with force and

displacement instruments. Geotextile grab specimens are rectangular in shape with dimensions of 102 by 203 mm (4 by 8 in.). Geotextile specimens are loaded in a tensile testing machine where the edges are clamped and the distance between the clamps is nominally 75 mm (3 in.). Rate of displacement during loading is 300 mm/min (12 in./min). Strength is reported in newtons per meter (pound (force) per inch).

ASTM D 4595-86, Standard Test Method for Tensile Property of Geotextiles by the Wide-Width Strip Method

In this standard test, a relatively wide specimen is gripped across its entire width and pulled at a constant rate of displacement until rupture occurs. The test specimen is square in shape with dimensions of 200 by 200 mm (8 by 8 in.). A monotonically increasing load is applied to the test specimen in a tensile testing machine. The distance between the clamps at the start of the test is 100 mm (4 in.) and the specimen is strained at a rate of 10 percent per minute. Tests may be conducted with the specimen in a wet or dry condition. The average breaking force in N/m (lbf/in.) and the average percent elongation at the breaking force are measured and reported.

ASTM D 4533-91, Standard Test Method for Trapezoidal Tearing Strength of Geotextiles

In this test, a geotextile test specimen that is 76 mm (3 in.) wide by 200 mm (8 in.) long is set up in a tensile testing machine with jaws clamped on a nonparallel section, as shown in Figure A1, and pulled to force a tear through the section. A notch 15 mm deep is cut in the center of the trapezoidal section to ensure that the tear starts in the center of the test section. The clamped specimen is pulled at a nominal rate of 300 mm/min (12 in./min) to force a tear across the section while the resistance to tearing is measured. The test is conducted in an environment where air temperature is maintained at 21 ± 2 °C (70 ± 4 °F) with a relative humidity of 65 ± 5 percent. Tearing strength is reported as force in newtons (pound force).

ASTM D 4833-88, Standard Test Method for Index Puncture Resistance of Geotextiles, Geomembranes, and Related Products

In this test method, a test specimen of geotextile is clamped without tension between circular plates in a ring clamp to expose a circular section of geotextile that is 37 mm (1.5 in.) in diameter. The clamp stand is secured to the platen of a load testing machine. A solid steel rod that is 8 mm in diameter is forced against the

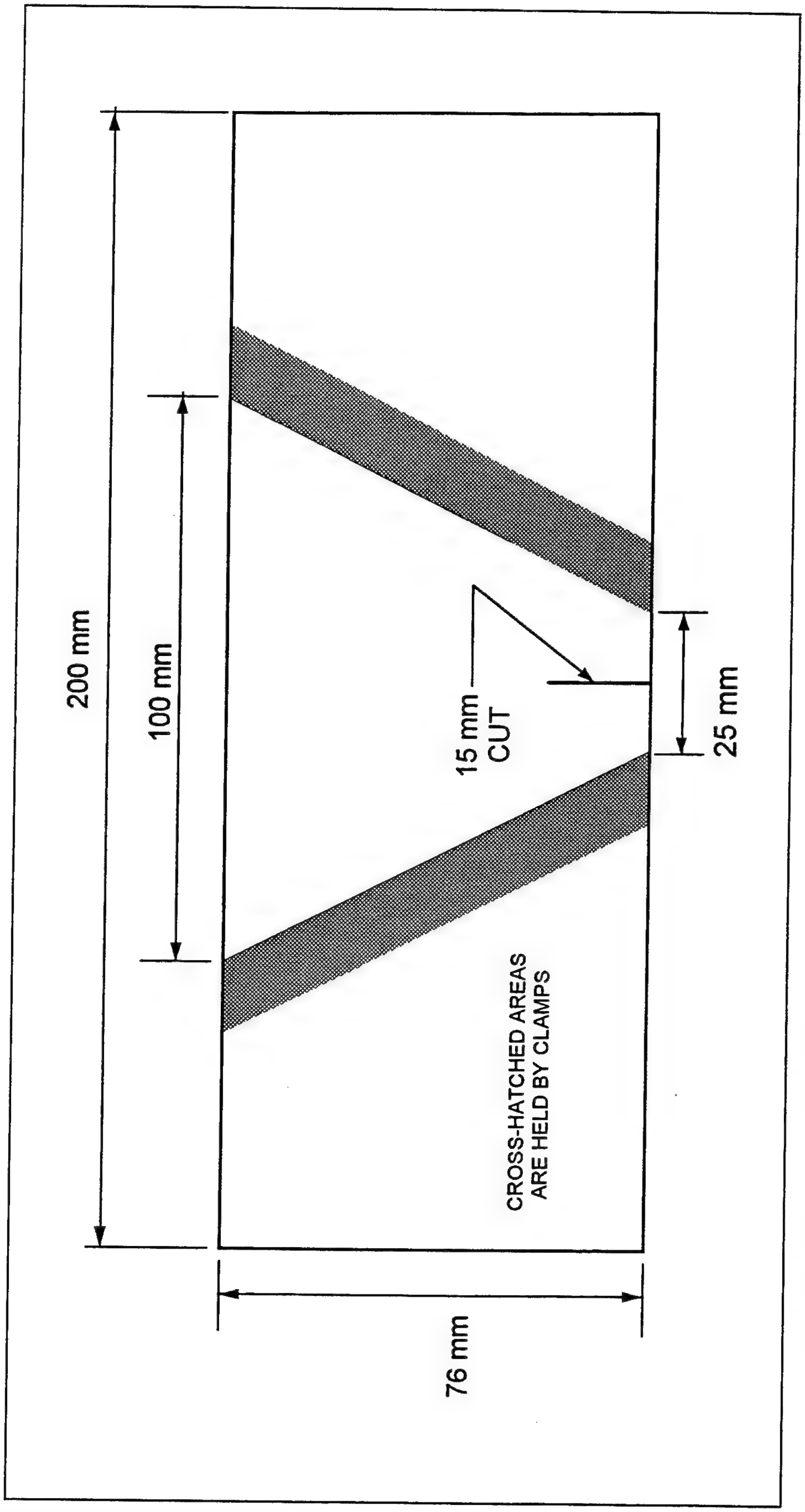


Figure A1. Geotextile specimen configuration for tearing strength test

center of the unsupported geotextile test specimen until rupture occurs. The puncture rod is forced against the geotextile at a nominal rate of 300 mm/min (12 in./min) until the test specimen is completely ruptured. Force is recorded continuously as the puncture rod passes through the geotextile surface. The intention of the test is to measure puncture resistance of the yarn; therefore, tests are discarded where the rod slips between the yarns without causing breakage. The test is conducted in an environment where air temperature is maintained at 21 ± 2 °C (70 ± 4 °F) with a relative humidity of 65 ± 5 percent. Average puncture resistance is reported as force in newtons (pound force).

ASTM D 3786-87, Standard Test Method for Hydraulic Bursting Strength of Knitted Goods and Nonwoven Fabrics--Diaphragm Bursting Strength Tester Method

In this procedure, a specimen of geotextile is clamped over a circular expandable diaphragm. The diaphragm is expanded by fluid pressure to the point that the specimen ruptures. The fabric bursting pressure is reported as the difference between the total pressure required to inflate the diaphragm and rupture the specimen and the pressure required to inflate the diaphragm.

ASTM D 4751-93, Standard Test Method for Determination of Apparent Opening Size of Geotextiles

The apparent opening size (AOS) is the approximate size of the largest particle that passes through a geotextile as given in U.S. sieve sizes. The AOS is determined by sieving glass beads through the openings in the geotextile of interest. The test is performed by placing a geotextile specimen in a sieve frame and glass beads on the geotextile surface. The geotextile and frame are then shaken in such a manner that the beads pass through openings in the test specimen. The procedure is repeated using the same specimen but with glass beads of various sizes until the AOS has been determined. Temperature and relative humidity may affect these test results, so this test is conducted in an environment where air temperature is maintained at 21 ± 2 °C (70 ± 4 °F) with a relative humidity between 50 and 70 percent.

ASTM D 4355-92, Standard Test Method for Deterioration of Geotextiles from Exposure to Ultraviolet Light and Water (Xenon-Arc Type Apparatus)

In this test, deterioration in tensile strength caused by exposure to ultraviolet light and water are simulated using a Xenon-arc light source along with intermittent water spray. Test specimens of geotextiles in the machine and cross directions are exposed to 2-hr cycles of light and water. A cycle consists of subjecting the geotextile to 90 min of light exposure and 30 min of water spray exposure. The samples are subjected to light and water exposure for 0, 150, 300, and 500 hr. Following exposure, tensile strength of the exposed specimens is determined along with that of unexposed test specimens to serve as controls. The specimens are cut into 2-in.-wide strips and tested with a distance between clamps of 75 mm (3 in.). Tensile strengths of control specimens are compared with those of the exposed specimens from both the machine and cross directions. Deterioration is quantified as the percent strength of the test specimens at various exposure times relative to the controls.

ASTM D 4491-92, Standard Test Method for Water Permeability of Geotextiles by Permittivity

One of the major advantage of geotextiles is that they are pervious to water flow both across and within their manufactured plane. Therefore they facilitate drainage and increase the strength of soil. Permeability, as used in the context of this work, is an index of the ease with which water flows through a geotextile. Since geotextiles are of various thicknesses, evaluation of permeability in terms of the Darcy coefficient of permeability can be misleading. It is more worthwhile, in many instances, to evaluate the quantity of water that flows through a geotextile under a particular (pressure) head over a particular cross-sectional area. This measurement is expressed as permittivity. If the permeability of a particular geotextile is necessary or desired, a nominal coefficient of permeability may be obtained by multiplying permittivity by the nominal thickness of the geotextile.

Quantities that must be known or measured to determine permittivity are:

a. Volume of water, V, that flows through the geotextile during the test period.

b. Area through which flow occurs, A.

c. Time, τ, during which flow occurs .

d. Pressure head causing flow, Δh.

e. Thickness of the geotextile, T.

Pressure head, Δh, is computed by dividing the applied gage pressure (in appropriate units) by the density of water. Flow, q, as volume per unit time is

$$q = \frac{V}{\tau} \tag{A1}$$

and permittivity, Ψ, is

$$\Psi = \frac{q}{\Delta h \ A} \tag{A2}$$

The measurement of water flow through a geotextile during determination of permittivity should, ideally, be conducted under conditions of complete water saturation. Measures such as the application of vacuum should be taken to remove air from the piping system and geotextile before testing. Such measures are necessary because surface tension between air and water causes entrapped air bubbles not removed from the geotextile to tightly block off sections of the test specimen through which flow would otherwise occur. Consequently, the presence of air adversely affects measurement of permittivity.

Appendix B
Consideration of Arching

Arching is defined as the ability of a material to transfer loads from one location to another in response to a relative displacement between the locations. A system of shear stresses is the mechanism by which the loads are transferred as the results of arching (McNulty 1965). Arching is classified as active when the area or volume of interest undergoes a decrease in stress and as passive when stress is increased.

Terzaghi and Peck (1948) used a simple laboratory experiment to explain the arching phenomenon; Figure B1 illustrates the test performed and depicts a layer of sand placed on a platform containing a trapdoor overlying a cavity (line ab in Figure B1). Pressure on the platform is measured with a scale mounted underneath the door. The depth, H, of the associated layer of sand is several times greater than the width of the trapdoor. As long as the trapdoor is held in its original position, pressure on the trapdoor as well as on the adjoining platform is equal to γ H per unit area. However, as soon as the door is allowed to move downward, pressure on the door decreases to a small fraction of its initial value, whereas pressure on the adjacent platform increases, as shown in Figure B1. This is due to the fact that the downward movement of the column of sand above the yielding trapdoor is resisted by shearing stresses along its lateral boundaries, ac and bd. It is well to note here that Terzaghi and Peck (1948) state that ultimate load on a trapdoor does not exceed the weight of a half cylinder having a diameter that is the width of the trapdoor (i.e, the shaded area aeb shown in Figure B1). If the soil in question has some slight cohesion, the trapdoor can be removed completely and the soil will bridge the gap and not fall through. As discussed earlier, the Marina del Rey sand has apparent cohesion that arises as the result of incomplete saturation caused by gas in the pores; cohesion or apparent cohesion enhances the effects of arching. Pressure or load that is not supported by a trapdoor that moves downward is carried by arching action into the abutments.

Terzaghi (1943) presents an extensive discussion of trapdoor arching as well as various theories available to compute the ultimate load on a yielding trapdoor. One theory of arching that assumes vertical slip planes above the edges of the trapdoor

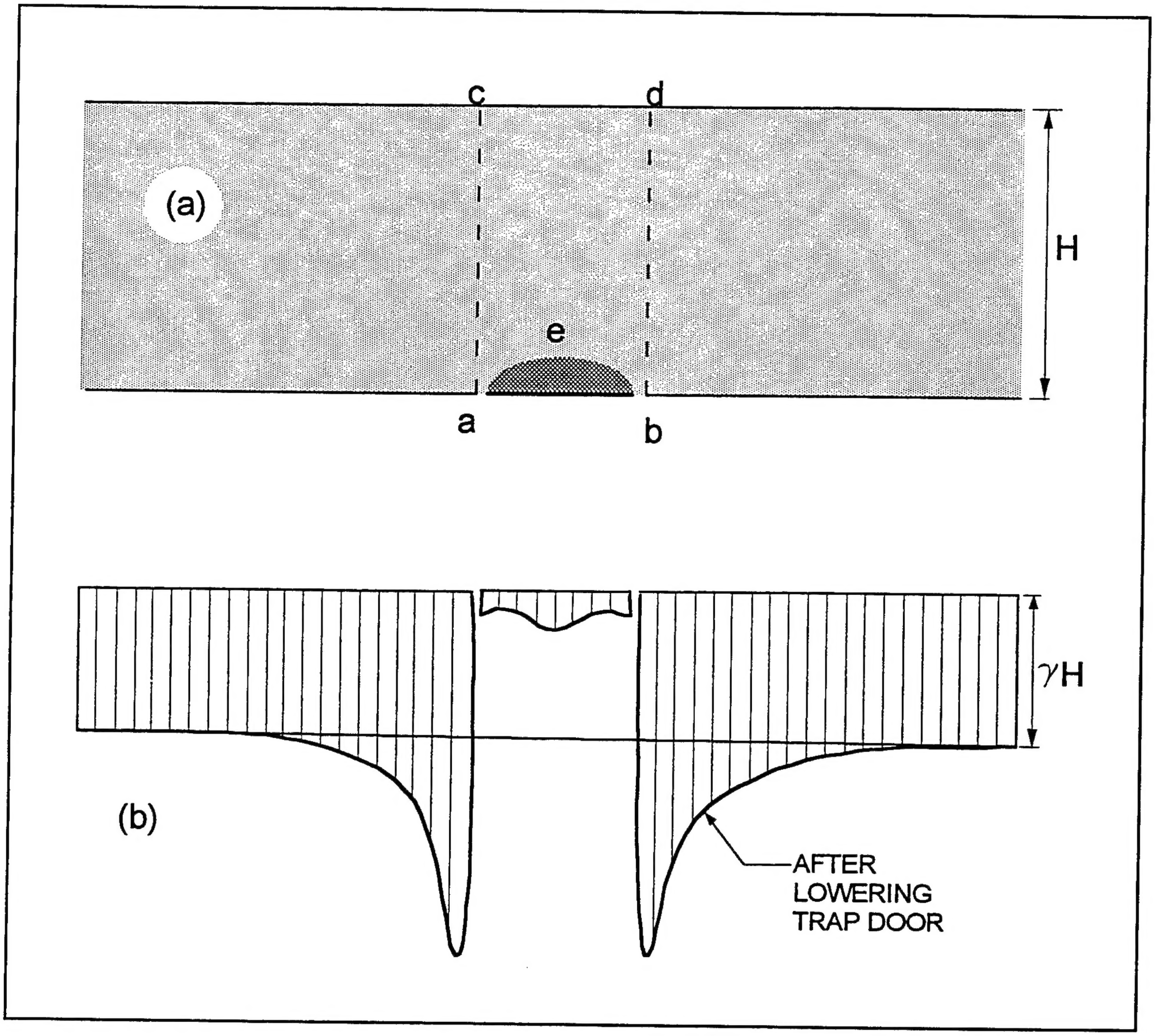


Figure B1. (a) Apparatus for investigating arching in layer of sand above yielding trapdoor ab. (b) Pressure on platform and trapdoor after slight lowering of door (Terzaghi and Peck 1948)

and one that is known to predict reasonable values of the arching ratio,[1] is developed in detail (by Terzaghi 1943) for soil in a state of plane strain with both frictional and cohesive components. When applied to a soil with an angle of internal friction of 30 to 40 deg, the theory predicts that soil cover two to three door widths deep will allow the trapdoor load to diminish to a value of about 30 percent of the dead load because of active arching, and the load remains constant with further increases in depth. In an investigation to study arching, McNulty (1965) tested two cohesionless (purely frictional) soils under axisymmetric and plane strain conditions; his results show that, in active arching, as the ratio of height to door diameter or width (H/B)

[1] Arching ratio is defined to be the ratio of load on the (slightly) lowered trapdoor to load on the undeflected platform.

increases, arching ratio decreases. These results by McNulty (1965) are summarized in Figure B2 and suggest a clear propensity for arching where H/B ratios are greater than about 1.5. Geometry of the scow hoppers used at Marina del Rey is such that the H/B ratio is of the order of 1.5; analysis and experimental studies (by McNulty 1965 and Terzaghi 1943) suggest that arching is probable at this H/B ratio and becomes more severe as the ratio increases to about 3.

The implication of this analysis is that arching will affect the propensity of cohesionless materials to flow freely through trapdoor orifices from bins if the soil friction angle is greater than 30 deg. If such materials must be discharged from hoppers, then the notion of arching must be considered and the H/B ratio and other factors (such as cohesion) controlled appropriately; otherwise there is the risk of

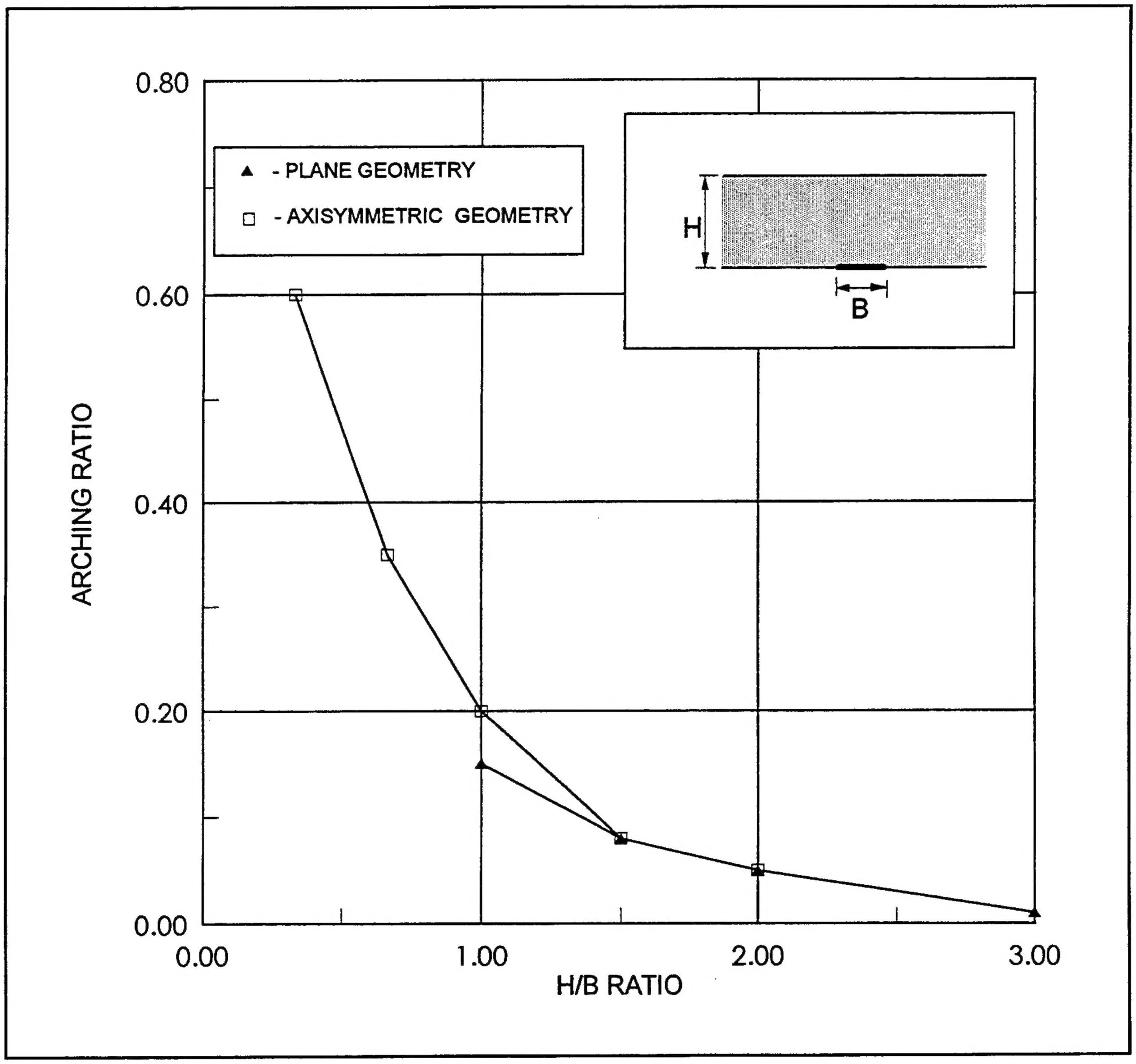


Figure B2. Arching ratio versus soil height to opening size ratio (McNulty 1965)

such frictional materials becoming lodged in the hopper. It is possible, then, that arching did contribute to a greater or lesser extent to the first geocontainer® becoming lodged in the scow at Marina del Rey because:

a. The hopper was filled to within 5 ft of the top during the first loading; therefore the H/B ratio was greater than 1.5.

b. The material was a clean, medium dense, subangular sand with an angle of internal friction, ϕ, probably greater than 30 deg.

c There was likely apparent cohesion in the sand mass because of gas present in the voids in the form of air (because water was allowed to drain from soil in the bucket during dredging and placement), and methane and hydrogen sulfide (because of organic material degradation).

Injecting water into the soil mass with diffusers to free the container lodged in the scow hopper worked to:

a. Break up the arches formed as the result of overfilling the hopper.

b. Effectively decrease shear stresses within the soil mass.

c. Increase the degree of saturation of the soil to reduce apparent cohesion/negative pore water pressure.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
July 1997

3. REPORT TYPE AND DATES COVERED
Final report

4. TITLE AND SUBTITLE
Development and Demonstration of Dredged Material Containment Systems Using Geotextiles

5. FUNDING NUMBERS

6. AUTHOR(S)
Paul Gilbert, Jack Fowler, Ed Trainer

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Nicolon Corporation
Norcross, GA
U.S. Army Engineer Waterways Experiment Station
3909 Halls Ferry Road, Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER
Technical Report CPAR-GL-97-3

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Corps of Engineers
Washington, DC 20314-1000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Construction guidelines and techniques for the use of geotextile encapsulated soil elements to contain soil for underwater placement or for use as structural units are described. Additionally, geotextile products, techniques for construction using geotextiles, and experiences at several field sites are described. Properties and characteristics of geotextiles used for construction during the course of this investigation are discussed and described. Pertinent ASTM standard tests for measuring and specifying various geotextile properties and characteristics are identified and discussed. GeoCoPS, a public domain computer code for design and analysis of long geotextile tubes, is described and used to emphasize the danger of rupturing long geotextile tubes if applied internal pressure exceeds the design value. Safety factors for long tube design are discussed in connection with GeoCoPS. Several case histories are summarized with a discussion of lessons learned from experiences surrounding construction activities, including filtration demonstrations at Nippersink Lake, near Fox Lake, IL, underwater contraction dike construction at Red Eye Crossing, near Baton Rouge, LA, and dredged material encapsulation for deep water placement at Marina del Rey, near Los Angeles, CA, and New York Harbor, at New York, NY.

14. SUBJECT TERMS

Encapsulated soil	Geotextiles
Geobag®	Geotube®
Geocontainer®	Slurry

15. NUMBER OF PAGES
84

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT
UNCLASSIFIED

18. SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

19. SECURITY CLASSIFICATION OF ABSTRACT

20. LIMITATION OF ABSTRACT